AD/A-005 017

DETERMINATION OF OPTIMUM TROPIC STORAGE AND EXPOSURE SITES. REPORT II. EMPIRICAL DATA

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APO New York 09827

March 1974

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TECOM Project No. 9 CO 009 000 006	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER AD/A-005017
4. TITLE (and Subtitle) DETERMINATION OF OPTIMUM TROPIC AND EXPOSURE SITES REPORT II: EMPIRICAL DATA		5. TYPE OF REPORT & PERIOD COVERED Final Report—February 1971 through December 1973
		6. PERFORMING ORG. REPORT NUMBER USATTC Report No. 7403001
7. AUTHOR(s) J. F. Sprouse M. D. Neptune J. C. Bryan		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Tropic Test Center STETC-AD APO New York 09827		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Test and Evaluation Command AMSTE-ME Aberdeen Proving Ground, MD 21005		12. REPORT DATE March 1974
		13. NUMBER OF PAGES 104
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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Butyl	Duncan's Multiple Range Analysis	Inclination of exposure rates	Materials deterioration	Plastics
Canal Zone	Environmental effects	Jungle exposure sites	Metals	Polyvinyl chloride
Cast nylon	Exposure sites	Latex	Microbial deterioration	Rainfall
Corrosion	Fungus coverage	Mangrove exposure sites	Mild steel	Rubbers
Cotton	Humidity	Mangroves	Open exposure sites	Salt fall
Dry season, tropic			Outdoor weathering	Sheltered exposure sites

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The US Army Tropic Test Center initiated a project in February 1971 entitled, "Determination of Optimum Tropic Storage and Exposure Sites." A total of 238,850 microscopc, photographic, tensile strength, weight loss, reflectivity and transmissivity data points were collected during the course of this study. The objectives of this investigation were to: (a) determine the relative severity of environmental effects at experimental and established exposure sites and assign severity rates, (b) determine deterioration rates and patterns of six basic materials, (c) develop techniques for detecting early onset of deterioration, (d) survey the

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Item 19. (cont)

Solar radiation	Tropic Test Center
Tensile strength	Tropic testing
Textiles	Ultraviolet radiation
Tropic coastal exposure sites	Wet season, tropic
Tropic exposure sites	Worst-case testing
Tropic site severity	

Item 20. (cont)

existing literature that pertains to the deterioration of materials exposed in the tropics, (e) determine the effects of tropic wet and dry seasons on deterioration, and (f) use the results to develop or update applicable storage and exposure Test Operation Procedures.

The investigation used nine experimental field test sites, seven established sites having past histories of use for tropic testing, and one air-conditioned control site for measuring site severity rates and patterns. The test sites existed throughout the Canal Zone on the Pacific coast, Atlantic coast and approximately at mid-Isthmus. Six basic materials representing three general material classes—textiles, metals and rubber—were used as indicators of site severity. These basic materials were cotton, polyvinyl chloride, nylon, latex rubber, butyl rubber and carbon steel. Materials were exposed at the tropic test sites for periods of 1 to 48 weeks during four seasonal exposure phases with tensile strength, corrosion weight loss, and microbial coverage used as experimental measurements of site severity. Results showed that individual tropic exposure sites do not provide uniform severity to all materials.

The study provides tables of sites generally homogeneous in deterioration for steel, cotton, nylon, polyvinyl chloride and latex rubber. It also gives severity comparisons between experimental and established sites, Atlantic versus Pacific sites, and sites with different degrees of natural and man-made protection from the environment, such as lean-to shelters, the natural jungle canopy, open grasslands, coastal sites, and mangrove forest (swamp).

The study shows that new experimental sites not previously used for tropic testing caused more rapid material deterioration for steel, nylon, and polyvinyl chloride while established sites were more severe for cotton and latex. Relative differences in site severity were not isolated for butyl rubber.

Sites on the Atlantic and Pacific sides of the Isthmus were generally equal in severity on a representative cross section of types of materials.

Comparisons of sites within different exposure modes (i.e., shelter, tropic forest, grassland, coastal and mangrove modes) demonstrated a general modal homogeneity for severity based on tensile strength and microbial coverage measurements.

The selection of "worst case" exposure sites in the tropics cannot be made solely on the basis of climatic severity. Within a tropical area, other aspects of the microenvironment are more significant than heat and humidity.

Finally, the study provides tables which recommend tropic test sites for metals, textiles, plastics and rubber materials to obtain major, moderate and minor deterioration severity.

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PREFACE

The present study lasted nearly three years including the planning, fieldwork and data analysis portions. During this time many persons who do not appear as authors made significant contributions. Initiator of the work was Benjamin S. Goodwin, Chief Engineer, US Army Test and Evaluation Command. Other contributors include Roger L. Williamson, George W. Gauger, George F. Downs III, Dr. W. H. Portig, CPT J. L. DiBenedetto, 1LT W. F. Lawson III, SP5 K. Griffis and SP5 W. Hopfer, all of the US Army Tropic Test Center staff. The study was conducted under the technical supervision of Dr. D. A. Dobbins, Chief, Test Analysis Branch.

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SECTION 1. INTRODUCTION

The fact that corrosion and deterioration occur at increased rates in the tropics results in high dollar losses to the United States military services each year. Deterioration appears in many forms. For example, unprotected optical devices become permanently fogged because of fungal attack when exposed or stored in a tropic environment. Many plastics undergo changes caused by solar radiation, moisture absorption, oxidation, and chemical attack. The surfaces of these plastics become rough and discolored, and ultimately lose dimensional stability. Medical supplies packaged in sealed containers and stored in noncontrolled environments absorb moisture and deteriorate. Untreated leather and textiles lose strength, change texture, and become mildewed and unserviceable. Paints and other protective coatings flake and crack, and heavily plated metal surfaces corrode or rust. Electronic components may change their characteristics so drastically that their outputs are unreliable. Capacitors malfunction, life of dry cell batteries is reduced, quartz crystals etch, transformers fail because of insulation breakdown, and solder joints corrode in the tropics. These are only a small portion of tropic failures which commonly occur and add up to high dollar losses in military equipment.

This investigation differs from most prior research in tropic deterioration of materials because deterioration rates were used primarily to assess severity of humid tropical locations used by the United States Army for determining durability of equipment. The intrinsic durability of the experimental samples was of secondary importance. Prior investigations concentrated on studying material characteristics and deterioration patterns. A major reason for this site-centered investigation was the requirement of materiel developers to shorten the materiel acquisition cycle by accelerating natural exposure tests as much as possible.

Historical Summary of Tropic Exposure in the Canal Zone

The first exposure site designed for conduct of scientific investigations by the United States Army on the deterioration of materials in the Canal Zone was an exposure site established at Barro Colorado Island in 1944. In late 1944, a survey team from Frankford Arsenal chose another site for testing at Fort Sherman on the Caribbean side of the Isthmus and began tropic tests by early 1945. Frankford Arsenal personnel left at the end of WWII and the Barro Colorado Island site was subsequently closed. However, Frankford Arsenal personnel have continued to use the Fort Sherman site and other sites in a nonresident capacity.

In 1953, the Naval Research Laboratory acquired a corrosion laboratory formerly operated by the Panama Canal Company at Miraflores on the Pacific side of the Isthmus. From 1953 until 1965, the laboratory was mainly concerned with a corrosion program involving environmental exposure tests of various metals and alloys.

In 1952, the US Army Chief of Staff became concerned with the limited area of test efforts in materials exposure conducted in the Canal Zone by the Army Technical Services. Testing by the Corps of Engineers and the Chemical and Quartermaster Corps was focused primarily on static exposure tests. A decision was reached to create an

"Army Tropical Test Station" for performing engineering and user tests of materiel as well as static exposure tests. The plan remained unfulfilled because of fund reductions until 1959 when the Army Scientific Advisory Panel strongly recommended a Tropic Test and Research Center. As a result, the proposed Army Tropic Test Center was created in 1962. In 1965, the corrosion laboratory operated by the Naval Research Laboratory at Miraflores was transferred to the Tropic Test Center and was redesignated a chemical, microbiological, and materials laboratory.

Statement of the Problem

Despite the fact that exposure research has continued since 1944, the role that different tropic subenvironments play in establishing deterioration rates of materials has not been adequately identified. This lack of knowledge has precluded the optimum selection of storage and exposure sites for either accelerated or representative material testing.

Tropic storage and exposure sites currently used by the Tropic Test Center have not been identified by severity for the following reasons:

- Test items have been exposed in a few areas only in close geographic proximity.

- Deterioration of test items has been frequently determined by visual observation.

- Test end-items, frequently limited in number, have not been subjected to destructive testing because of cost considerations and quantity limitations.

- The comparative effects of open, sheltered and forested exposure and storage have not been systematically determined.

Objectives

The principal objectives of this investigation were to:

- Determine the relative severity of environmental effects at experimental and established exposure sites and assign severity rates.

- Determine the deterioration rates and patterns of six basic materials.

- Develop techniques for detecting early onset of deterioration.

- Determine the effects of tropic wet and dry seasons on deterioration.

- Survey existing literature that pertains to the deterioration of materials exposed in the tropics. Note: Results of this objective are published in USATTC Report No. 7304001, "*Determination of Optimum Tropic Storage and Exposure Sites, Report I: Survey of Programs in Tropic Materials Research*" (reference 20).

- Incorporate the results, if sufficiently definitive, into new storage and exposure Test Operations Procedures.

SECTION 2. DETAILS OF INVESTIGATION

Selection of Materials for Exposure

Six materials were selected for exposure. Since most tropic deterioration begins as surface effects, all material samples were prepared in strip form, 26 inches by 2 inches, for effective observation and analysis. Exposure samples were selected to meet the following criteria:

- Show sufficiently rapid deterioration to detect seasonal variations.

- Allow measurement of deterioration with sufficient accuracy that measurement errors would not mask small differences in deterioration.

- Represent materials commonly used in the manufacture of military materiel.

The specific materials used were (1) cotton; white Army engineer tape, conforming to Federal Spec. DDD-T-86(F); (2) butyl rubber; strips, 1/32-inch thick, conforming to ASTM D1418, IIR; (3) natural rubber (latex); strips, 1/32-inch thick, conforming to ASTM D1418, NR; (4) mild steel; strips 0.0050-inch thick, composition conforming to AISI 1006 carbon steel; (5) cast nylon; strips, 0.010-inch thick, conforming to MIL STD N-18352; (6) polyvinyl chloride; plasticized strips, 0.014-inch thick, conforming to ASTM D1593.

Many other basic materials used in the fabrication of military items were logical candidates for selection in this investigation, but selection was restricted by limited time and funding.

Selection and Environmental Characterization of Exposure Sites

Sixteen field exposure sites and one laboratory control site were used in this study; their identification and locations are shown in figure 1. The field test sites were selected across the Isthmus from the Atlantic to the Pacific coasts in an effort to expose materials to as many different tropic subenvironments as possible under fund and time constraints. The field sites included seven established exposure sites, used previously for materiel tests and static exposure, and nine new experimental sites. The sites were divided into four modes: open, coastal, sheltered and forest. Open sites consisted of exposure racks located at inland open sites, coastal sites included one on the Atlantic and one on the Pacific ocean; sheltered sites contained exposure racks which were covered with an open-sided shed; and forested sites were tropical moist forests. Figures 2 through 6 are representative of the majority of the sites. Data summarizing the environmental characteristics of the experimental and established exposure sites compiled with respect to vegetation, soils, topography, climate, microbial activity and salt fall, are contained in table 1 and discussed in the following paragraphs.

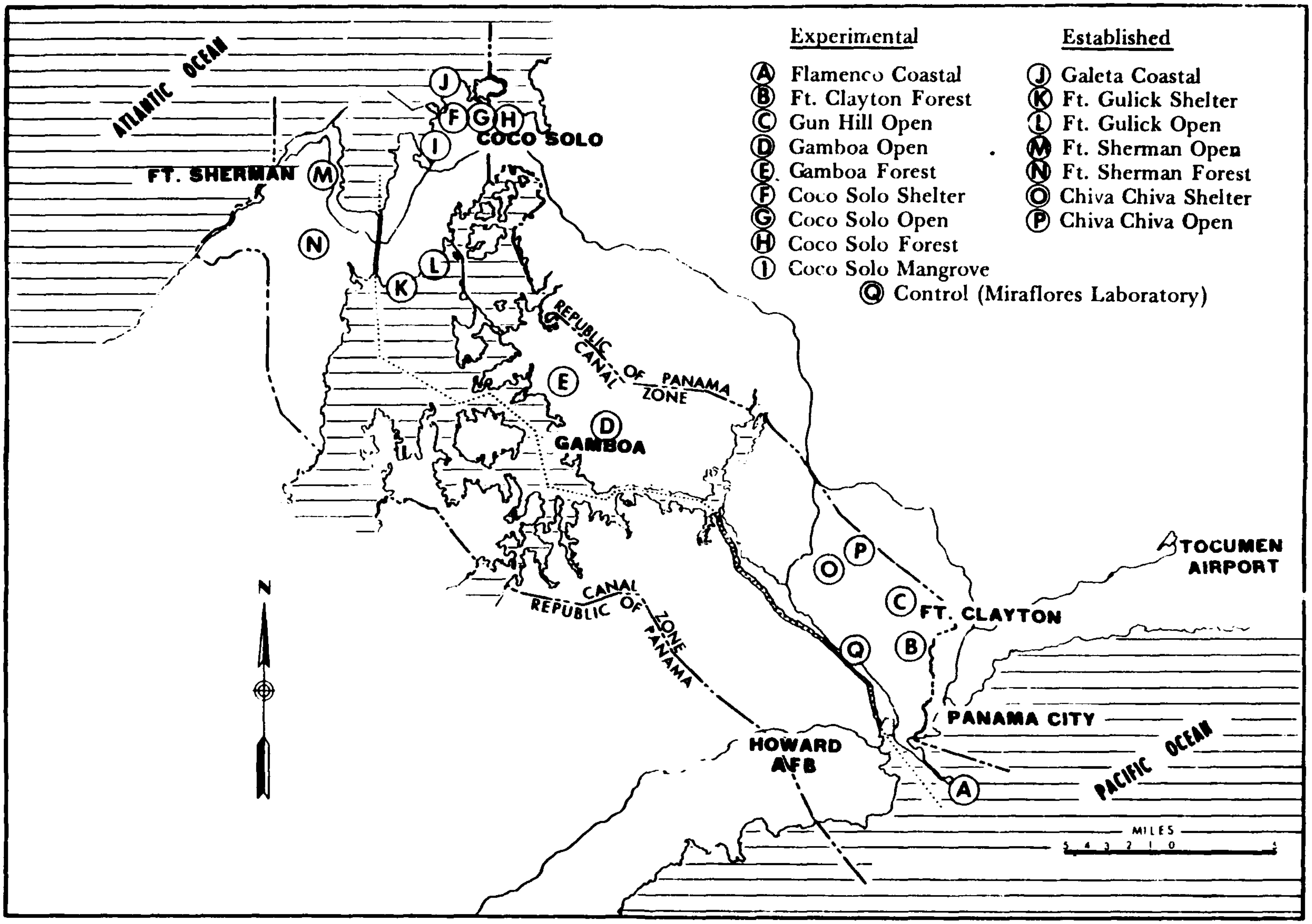

Figure 1. Locations of Experimental and Established Exposure Sites in the Canal Zone.

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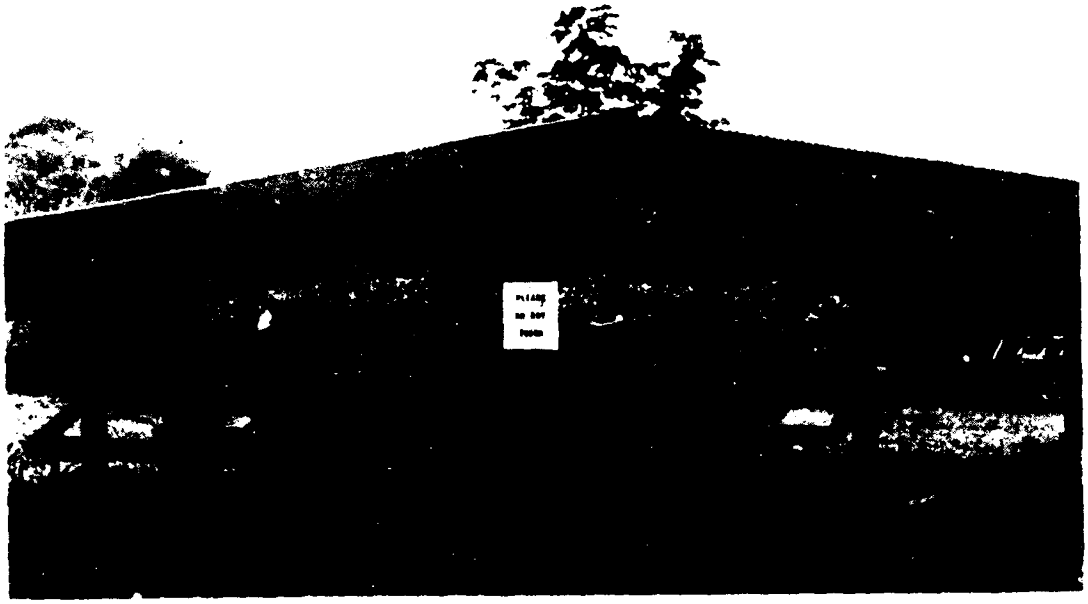

Figure 2. Experimental Shelter Site at Coco Solo (Atlantic Side of Isthmus)

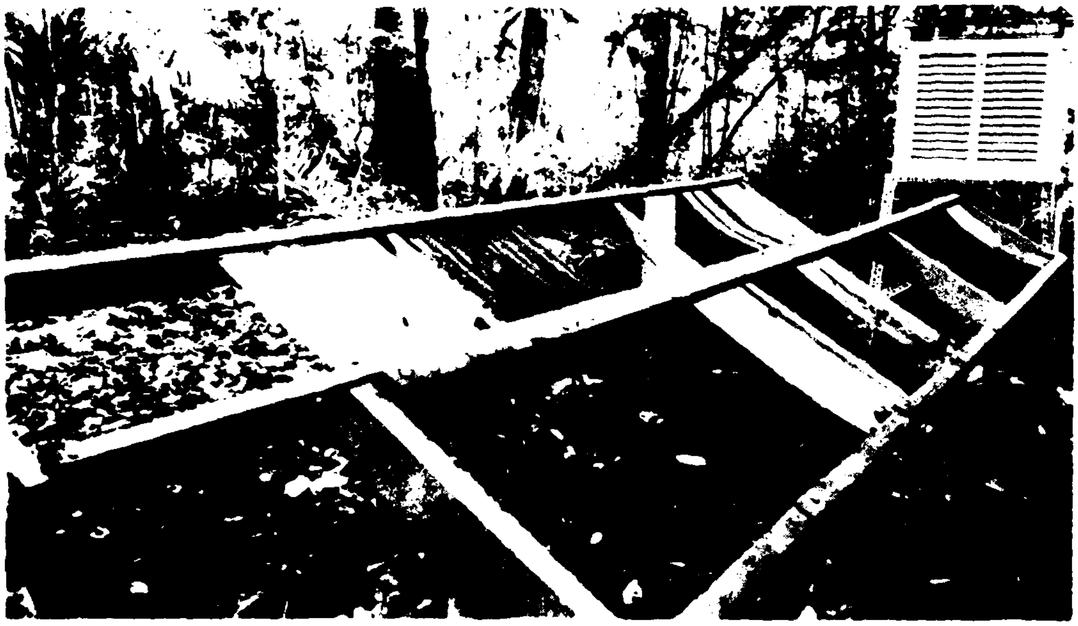

Figure 3 Experimental Forest Site at Gamboa (Mid-Isthmus)

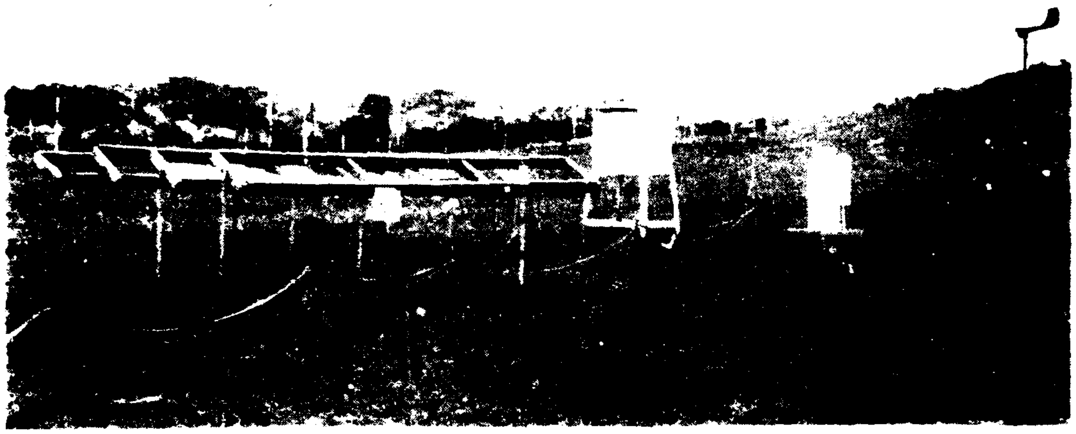

Figure 4. Established Open Site at Chiva Chiva (Pacific Side of Isthmus)

Figure 5. Experimental Open Site at Gun Hill (Pacific Side of Isthmus)

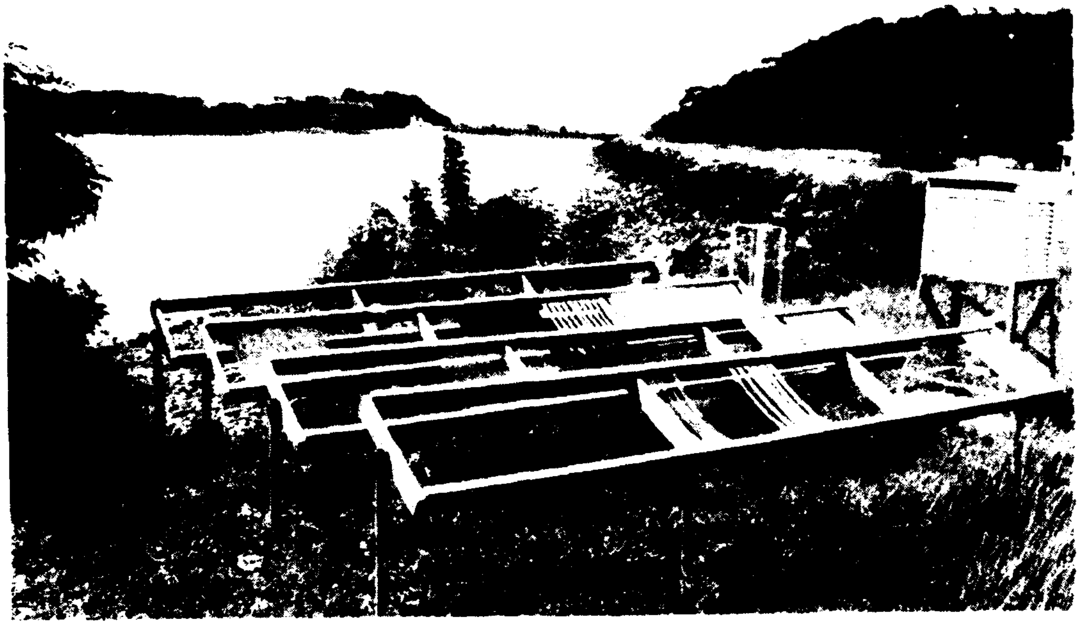

Figure 6. Experimental Coastal Site at Flamenco Island (Pacific Side of Isthmus)

• Vegetation

Vegetation characteristics at the individual sites were determined (where appropriate) according to maturity, species, stem diameter and height, and specie density by height class (reference 51). The vegetation in the forest exposure sites can be classified as tropical moist, using the Holdridge classification scheme (reference 34).

The Fort Clayton forest site is a tropic moist forest-dry transition, verging on a tropic dry forest. The Gamboa forest site is a nontransitional tropic moist forest. The Fort Sherman and Coco Solo sites are tropic moist forest-wet transitions. Because mangrove swamp is not dependent upon rainfall for its moisture, it can occur in any tropic forest type. The age of the forest sites varies from 25 to 100 years with the youngest occurring at the Fort Sherman site and the oldest at Gamboa. A taxonomic listing of trees, shrubs, vines and ground cover plants for each of these sites is shown in table C-1. Structural vegetation characteristics for each exposure site are provided in table 1.

• Soils and Topography

Soils and topography characteristics at the exposure sites were determined to provide exposure site definition for future reference.

Data are presented in table 1, giving average values for these characteristics at each site.

TABLE 1. SUMMARY OF ENVIRONMENTAL CHARACTERISTICS AT EXPERIMENTAL AND ESTABLISHED EXPOSURE SITES

	Forest (Tropical Moist Forest)					Shelter			
	Non-Transition		Wet Transition		Dry Transition				
Site. Site Coordinates:	Coco Solo Mangrove 233 359	Gamboa 382 125	Ft. Sherman 145 308	Coco Solo 248 367	Ft. Clayton 582 961	Coco Solo 248 368	Ft. Gulick 253 310	Chiva Chiva 563 979	Ft. Sherman 148 348
Vegetation									
Maturity	Mature	Approaching mature	Secondary	Approaching mature	Approaching mature	NA	NA	NA	Secondary growth
No. of Stems/hec	872	1065		914	378	NA	NA	NA	NA
Mean Stem Diameter, centimeters	14.1	7.8	5.9	26.6	9.6	NA	NA	NA	NA
Mean Stem Height, meters	11.4	11.2	8.5	10.5	12.3	NA	NA	NA	NA
Species Density by Height Class									
25–35 meters	3	10	0	4	1	NA	NA	NA	NA
10–25 meters	0	9	18	8	7	NA	NA	NA	NA
1–8 meters-shrubs	2	26	22	17	20	NA	NA	NA	NA
< 1 meter (B)	3	8	3	6	3	NA	NA	NA	NA
Vines	0	5	17	5	3	NA	NA	NA	NA
Soils									
Texture Class (USDA) Component Characteristics	Sandy loam	Silt loam	Loam	Clay loam	Clay loam	Clay loam	(C)	Sandy clay loam	Sandy loam
Percent Sand	76.0	23.4	41.4	36.4	30.4	24.4	NA	47.5	65.4
Percent Silt	7.0	51.8	33.0	36.0	31.6	36.0	NA	22.1	19.0
Percent Clay	17.0	24.8	25.6	27.6	38.0	39.6	NA	30.4	15.6
Soil Aerobic Bacteria X10^5 (F)									
Dry Season (D)	181.8	58.5	2.5	145.0	22.8	87.5	26.5	69.5	10.7
Wet Season (E)	342.9	150.4	16.5	180.0	99.7	64.6	43.4	110.0	12.5
Topography									
Landform	Tidal mud flat of low coastal plain	Rolling hills	Rolling hills	Side of a low rugged hill	Side of a low rugged hill	Open alluvial plain	Open alluvial plain	Open plain	Open alluvial plain
Slope Characteristics									
Percent Slope	0	0.5	3.5	14.0	29.5	0	0	2.5	0
Azimuth-Degrees	NA	270	275	250	310	NA	NA	135	NA
Meteorological									
Average Mean Daily Maximum Temperature (°F)									
Dry Season (D)*			82.4				86.5	88.3	88.0
Wet Season (E)	86.2	78.7	81.2	87.0	80.8	85.7	85.8	84.4	87.0
Average Mean Daily Minimum Temperature (°F)									
Dry Season (D)*			77.8				76.0	72.0	78.0
Wet Season (E)	76.0	72.4	77.6	71.4	74.4	73.6	75.8	72.6	74.6
Average Temperature (°F)									
Dry Season (D)*			79.6				80.0	78.8	82.0
Wet Season (E)	80.2	75.1	79.1	77.4	77.0	78.6	79.6	77.3	80.0
Average Mean Temperature Range (°F)									
Dry Season (D)*			4.6				10.5	16.5	10.6
Wet Season (E)	10.2	6.3	3.7	15.6	6.4	12.1	10.0	11.9	12.5
Average Mean Daily Minimum Relative Humidity (percent)									
Dry Season (D)*			77.6				66.3	55.3	75.0
Wet Season (E)	77.2	79.0	85.0	74.0	83.9	69.9	71.5	68.7	73.6

	Open					Coastal	
Site. Site Coordinates:	Coco Solo 248 368	Ft. Gulick 253 310	Gamboa 406 097	Chiva Chiva 563 979	Gun Hill 555 963	Galeta 247 395	Flamenco 625 849
Vegetation							
Maturity	Secondary growth	(C) NA	Secondary growth	Secondary growth	Secondary growth	Secondary growth	Secondary growth
No. of Stems/hec	NA	NA	155(A)	NA	NA	NA	NA
Mean Stem Diameter, centimeters	NA	NA	1.0	NA	NA	NA	NA
Mean Stem Height, meters	NA	NA	1.2	NA	NA	NA	NA
Species Density by Height Class							
25–35 meters	NA	NA	NA	NA	NA	NA	NA
10–25 meters	NA	NA	NA	NA	NA	NA	NA
1–8 meters-shrubs	NA	NA	NA	NA	NA	NA	NA
< 1 meter (B)	NA	NA	NA	NA	NA	NA	NA
Vines	NA	NA	NA	NA	NA	NA	NA
Soils							
Texture Class (USDA) Component Characteristics	Clay loam	(C)	Silty clay loam	Sandy clay loam	Sandy loam	Sandy loam	Sandy loam
Percent Sand	24.4	NA	18.4	47.5	71.6	67.3	55.4
Percent Silt	36.0	NA	42.4	22.1	19.1	17.0	28.0
Percent Clay	39.6	NA	39.2	30.4	9.3	15.7	16.6
Soil Aerobic Bacteria X10^5 (F)							
Dry Season (D)	87.5	26.5	61.9	69.5	60.9	14.4	251.4
Wet Season (E)	64.6	43.4	124.2	110.0	70.4	26.6	89.4
Topography							
Landform	Open plain	Open plain	Side of a low hill	Open plain	Level plateau on hilltop	Open alluvial plain	Open plain
Slope Characteristics							
Percent Slope	0	0	25	2.5	0	0	0
Azimuth-Degrees	NA	NA	182	135	NA	NA	NA
Meteorological							
Average Mean Daily Maximum Temperature (°F)							
Dry Season (D)*	88.8	88.8	88.6	90.0	88.4	86.0	86.8
Wet Season (E)	87.4	86.4	85.4	87.6	85.7	86.1	86.0
Average Mean Daily Minimum Temperature (°F)							
Dry Season (D)*	73.8	73.0	68.2	72.2	73.6	80.0	74.5
Wet Season (E)	72.9	71.3	70.8	73.3	72.3	74.7	77.0
Average Temperature (°F)							
Dry Season (D)*	79.6	79.4	77.2	79.6	79.0	82.5	79.0
Wet Season (E)	78.8	77.6	76.1	78.7	77.0	79.4	79.6
Average Mean Temperature Range (°F)							
Dry Season (D)*	15.0	15.8	20.4	17.8	14.8	5.5	[illegible]
Wet Season (E)	14.6	15.1	14.7	14.2	13.1	11.4	10.0
Average Mean Daily Minimum Relative Humidity (percent)							
Dry Season (D)*	65.3	62.0	60.4	[illegible]	66.0		63.8
Wet Season (E)	69.3	70.3	68.6	66.3	77.6	71.8	72.4

Table 1 (cont)

Site:	Forest (Tropical Moist Forest)					Shelter				Open					Coastal	
	Non-Transition		Wet Transition		Dry Transition											
Site Coordinates:	Coco Solo Mangrove 233 359	Gamboa 382 125	Ft. Sherman 145 308	Coco Solo 248 367	Ft. Clayton 582 961	Coco Solo 248 368	Ft. Gulick 253 310	Chiva Chiva 563 979	Ft. Sherman 148 348	Coco Solo 248 368	Ft. Gulick 253 310	Gamboa 406 097	Chiva Chiva 563 979	Gun Hill 555 963	Galeta 247 395	Flamenco 625 849
Meteorological (cont)																
Average Mean Daily Global Radiation (Langleys)																
Dry Season (D)*									465	513		394	430	452		410
Wet Season (E)*									367	327		333	359	339		404
Average Rainfall Per Month (inches)																
Dry Season (D)*									6.9	4.0	8.8	3.5	4.3	4.6	5.8	4.2
Wet Season (E)*									11.7	13.1	12.7	10.1	8.1	5.8	13.5	5.3
Salt Fall Mg/m²/day																
Dry Season (D)	26.8	8.9	14.1	11.9		13.3	16.9	21.8	43.4	13.3	16.9	10.7	21.8	12.1	605.8	14.7
Wet Season (E)	6.1	4.7	5.0	5.9	6.1	4.7	7.8	6.7	14.9	4.7	7.8	7.1	6.7	6.9	128.1	12.6
Average Number of Microorganisms in the Atmosphere/Month																
Dry Season (D)*																
Bacteria/100 liters of air	7.5	7.3	89.3	14.5	78.3	143.0	23.3	28.0		143.0	23.3	111.8	28.0	39.5	10.7	18.5
Fungi/100 liters of air	26.5	110.0	166.3	265.3	310.0	107.3	61.8	149.5		107.3	61.8	75.3	149.5	128.5	34.0	92.5
Wet Season (E)*																
Bacteria/100 liters of air	24.6	49.3	14.4	21.6	17.2	32.0	8.4	11.3		32.0	8.4	37.5	11.3	23.3	14.3	136.0
Fungi/100 liters of air	81.6	101.0	82.6	89.1	88.1	98.0	45.4	61.4		98.0	45.4	48.0	61.4	92.3	27.3	109.0

* Blank data spaces resulted from monitoring instrument malfunction or cancellation of requirement to monitor the specific parameter because insignificant ambient changes were occurring.

LEGEND:

NA = Not applicable
(A) = No. of grass stems/meter²
(B) = Numerous unidentifiable seedlings
(C) = Hard surface slag and gravel
(D) = Dry season, January - April
(E) = Wet season, May - December
(F) = Average number of bacteria per gram of dry soil

• Climate

The Canal Zone lies in the humid tropics. The time from mid-April through mid-December is usually characterized by frequent rains—the remainder of the year by less frequent and less abundant rains. The temperature and humidity fluctuations are minor and mainly confined to the diurnal variation. There is much cloudiness, and even during the dry season there is hardly ever a day that is cloud-free for 24 consecutive hours. Table C-2 shows the climatic conditions during the duration of this investigation. It also shows under "Special Periods" some changes in weather patterns as they occurred during the field exposure period.

Meteorological instruments to measure temperature, relative humidity, total radiation and amount of rainfall were placed at the major exposure sites. Data obtained are presented in table 1: mean daily maximum and minimum temperature, mean temperature, mean temperature range, mean daily minimum relative humidity, mean daily global radiation and rainfall data. Temperature and humidity were measured by means of Belfort hygrothermographs, rainfall with recording weighing gauges, and global radiation with Eppley pyranometers.

• Microbial Activity

Supporting data were collected at the exposure sites to define microbial activity in the soil and air. Soil samples were collected in an area adjacent to the exposure racks at the respective sites, returned to the laboratory and standard dilution techniques used for the enumeration of aerobic bacteria. The average number of colonies per gram of dry soil per site is shown in table 1.

The distribution of airborne microorganisms was determined at each exposure site. The data were collected using Test Operations Procedure 8-3-550, *Tropical Microbiological Air Sampling,* and presented in table 1, showing the average number of microorganisms per liter of air in the atmosphere per month per site.

• Salt fall

Chloride ion measurements were taken at all exposure sites by the wet candle method (references 16, 17). The measurements were based on a monthly exposure period, and results were reported as milligrams of chloride deposited per square meter (surface area of salt candle wick) per day. Data showing the average ambient chloride level per site for dry and wet seasons are in table 1. Data are presented in table C-2 to show average daily ambient levels for monthly salt candle exposure periods from June 1971 through May 1972.

<u>Exposure Racks and Sheds</u>

Four exposure racks were constructed at each of the exposure sites (figures 2–6). The frame of the racks consisted of painted 2- x 4-inch lumber supported by 1½-inch galvanized steel pipe. The racks were 14 feet long and 2 feet wide, inclined at 30° from horizontal, and were approximately 3 feet above ground at the lowest portion. All racks faced east. Test specimens passed between glass strips at both the top and bottom of the rack before being stapled to the rack frame. Glass strips were used in order that test samples could be held in place by a biologically inert material at both ends.

The exposure racks were constructed in such a way that they would fulfill, as closely as possible, the following three requirements: have sufficient inclination to facilitate the runoff of rain, have maximum exposure to solar radiation, and minimize seasonal variations of unobstructed solar radiation incident on the test specimens because of changing sun position. This last requirement allowed more emphasis to be placed upon seasonal changes of climate and weather.

Appendix D demonstrates why the racks, facing east and inclined 30° on the horizontal plane, produce very nearly the ideal situation and how these conditions were computed from the position of the sun.

Sheds constructed at selected sites (figure 2) consisted of wooden uprights covered with galvanized corrugated roofing. The sheds were 20 feet long, 20 feet wide and 6 feet high.

Sample Exposure Schedules

Exposure samples were cut to a standard length and width (26 inches by 2 inches), and attached to the exposure racks. One set, consisting of 12 individual specimens of each sample material, was stapled to the upper portion of the rack then passed between two glass plates at both the top and the bottom of the rack. A 200-gram weight was attached to the loose end of the individual sample so that a uniform stress was applied—then the sample was stapled at the lower portion of the rack.

The samples were emplaced on the following dates: Phase 1, 6 April 1971 (late dry season exposure); Phase 2, 6 July 1971 (early wet season exposure); Phase 3, 27 September 1971 (late wet season exposure); and Phase 4, 20 December 1971 (early dry season exposure). The samples emplaced 20 December 1971 were subjected to unusual seasonal rains in January, therefore additional steel samples were placed at selected sites on 7 February 1972 (Phase 5) in order to have an exposure phase beginning without heavy rain.

Samples were transported in individual plastic bags, and exposed samples retrieved according to the following schedule: latex and steel, weekly; cotton, every 2 weeks; nylon, polyvinyl chloride, and butyl rubber, every 4 weeks. This sample retrieval schedule provided maximum exposure duration of 12 weeks for latex and steel, 24 weeks for cotton, and 48 weeks for nylon, polyvinyl chloride, and butyl. A schedule for exposure sample emplacement and retrieval is given in table 2.

TABLE 2. SCHEDULE FOR SAMPLE EMPLACEMENT AND RETRIEVAL

1971, weeks 14–33

Phase	Week	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Phase 1	Latex	O	X	X	X	X	X	X	X	X	X	X	X	X							
Phase 1	Steel	O	X	X	X	X	X	X	X	X	X	X	X	X							
Phase 1	Cotton	O		X		X		X		X		X		X		X		X		X	
Phase 1	PVC	O				X				X				X				X			
Phase 1	Nylon	O				X				X				X				X			
Phase 1	Butyl	O				X				X				X				X			
Phase 2	Latex														O	X	X	X	X	X	X
Phase 2	Steel														O	X	X	X	X	X	X
Phase 2	Cotton														O		X		X		X
Phase 2	PVC														O				X		
Phase 2	Nylon														O				X		
Phase 2	Butyl														O				X		
Phase 3	Latex																				
Phase 3	Steel																				
Phase 3	Cotton																				
Phase 3	PVC																				
Phase 3	Nylon																				
Phase 3	Butyl																				
Phase 4	Latex																				
Phase 4	Steel																				
Phase 4	Cotton																				
Phase 4	PVC																				
Phase 4	Nylon																				
Phase 4	Butyl																				
Phase 5	Steel																				

1971, weeks 34–52

Phase	Week	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Phase 1	Latex																			
Phase 1	Steel																			
Phase 1	Cotton	X		X		X														
Phase 1	PVC	X				X				X				X				X		
Phase 1	Nylon	X				X				X				X				X		
Phase 1	Butyl	X				X				X				X				X		
Phase 2	Latex	X	X	X	X	X	X													
Phase 2	Steel	X	X	X	X	X	X													
Phase 2	Cotton		X		X		X		X		X		X		X		X		X	
Phase 2	PVC		X				X				X				X				X	
Phase 2	Nylon		X				X				X				X				X	
Phase 2	Butyl		X				X				X				X				X	
Phase 3	Latex						O	X	X	X	X	X	X	X	X	X	X	X	X	
Phase 3	Steel						O	X	X	X	X	X	X	X	X	X	X	X	X	
Phase 3	Cotton						O		X		X		X		X		X		X	
Phase 3	PVC						O				X				X				X	
Phase 3	Nylon						O				X				X				X	
Phase 3	Butyl						O				X				X				X	
Phase 4	Latex																			O
Phase 4	Steel																			O
Phase 4	Cotton																			O
Phase 4	PVC																			O
Phase 4	Nylon																			O
Phase 4	Butyl																			O
Phase 5	Steel																			

1972, weeks 1–24

Phase	Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Phase 1	Latex																								
Phase 1	Steel																								
Phase 1	Cotton																								
Phase 1	PVC		X				X				X														
Phase 1	Nylon		X				X				X														
Phase 1	Butyl		X				X				X														
Phase 2	Latex																								
Phase 2	Steel																								
Phase 2	Cotton																								
Phase 2	PVC			X				X				X				X				X				X	
Phase 2	Nylon			X				X				X				X				X				X	
Phase 2	Butyl			X				X				X				X				X				X	
Phase 3	Latex																								
Phase 3	Steel																								
Phase 3	Cotton	X		X		X		X		X		X													
Phase 3	PVC			X				X				X				X				X				X	
Phase 3	Nylon			X				X				X				X				X				X	
Phase 3	Butyl			X				X				X				X				X				X	
Phase 4	Latex	X	X	X	X	X	X	X	X	X	X	X	X												
Phase 4	Steel	X	X	X	X	X	X	X	X	X	X	X	X												
Phase 4	Cotton		X		X		X		X		X		X		X		X		X		X		X		X
Phase 4	PVC				X				X				X				X				X				X
Phase 4	Nylon				X				X				X				X				X				X
Phase 4	Butyl				X				X				X				X				X				X
Phase 5	Steel						O	X	X	X		X	X	X	X	X	X	X	X						

1972, weeks 25–48

Phase	Week	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Phase 1	Latex																								
Phase 1	Steel																								
Phase 1	Cotton																								
Phase 1	PVC																								
Phase 1	Nylon																								
Phase 1	Butyl																								
Phase 2	Latex																								
Phase 2	Steel																								
Phase 2	Cotton																								
Phase 2	PVC																								
Phase 2	Nylon																								
Phase 2	Butyl																								
Phase 3	Latex																								
Phase 3	Steel																								
Phase 3	Cotton																								
Phase 3	PVC			X				X				X													
Phase 3	Nylon			X				X				X													
Phase 3	Butyl			X				X				X													
Phase 4	Latex																								
Phase 4	Steel																								
Phase 4	Cotton																								
Phase 4	PVC				X				X				X				X				X				X
Phase 4	Nylon				X				X				X				X				X				X
Phase 4	Butyl				X				X				X				X				X				X
Phase 5	Steel																								

LEGEND O = Samples Placed
X = Samples Retrieved

Laboratory Procedures

Exposed samples were returned to the laboratory for analysis after the selected exposure time. Microbiological, visual observations, nondestructive and destructive tests were performed to determine deterioration rates and patterns. Color photographs were taken to provide a permanent record of the visible deterioration. A flow diagram showing the analyses performed on each material and the number of data points obtained is shown in figure 7.

- Microbiological Procedure

An area approximately 1.5 centimeters square was aseptically removed from each exposed sample and its front surface placed against sterile carrot agar medium. Another square was cut from the same sample, and the back surface placed against the same carrot agar. This method was used for all samples with the exception of steel. The inoculated plates were then incubated at 27°C for 96 hours and the fungi and bacteria which grew were counted. The fungi were identified with the aid of a microscope. The various genera of fungi observed on all materials were taxonomically classified, primarily on morphological characteristics, as described by Barnett (reference 7), Gilman (reference 26), Clements, et al. (reference 15), Hawker (reference 33), and Breed, et al. (reference 12). The older taxonomic nomenclature was revised from Martin and Skirman (reference 39). Bacteria were not identified.

- Visual Observations

Visual observations of all exposed samples were conducted using a stereozoom, 7x to 30x, light microscope. Percent of area affected, whether it was microbiological growth, accumulated debris or material substrate change, was based on visual observations. The method followed the White Sands Missile Range Microbiological Test Evaluation Scheme (Proposed) (table C-3).

- Light Reflectance and Transmission Measurements

Reflectance characteristics of cotton, butyl rubber and latex rubber were measured in the visible light region of the spectrum. Transmission characteristics of polyvinyl chloride and nylon were used as an attempt to identify a reliable, early, nondestructive indicator of deterioration. Note: Reflectance and transmission data are not included in this report, those data will be analyzed and reported in later studies.

- Tensile Testing

All exposed samples were tensile-tested with the exception of those in advanced states of deterioration when extreme fragility prevented the preparation of a tensile specimen. Testing was conducted for the purpose of evaluating the effects of exposure on the mechanical properties of the materials. All tensile testing was completed according to American Society for Testing and Materials (ASTM) standard procedures; D259 for cotton (reference 4), D412 for the rubber specimens (reference 3), E345 for steel

Latex and Butyl

Analysis step	Number of Data Points: Latex	Number of Data Points: Butyl
FIELD PICK UP		
PLATED FOR MICROORGANISMS	8,160	8,160
PHOTOGRAPHED		
MICROSCOPIC EXAMINATION	14,688	14,688
CUT		
TENSILE STRENGTH MEASURED	9,806	4,896
CUT		
REFLECTIVITY MEASURED	12,268	4,896
TOTAL	44,942	32,640

Steel

Analysis step	Number of Data Points
FIELD PICK UP	
PHOTOGRAPHED OVERALL	
MACROPHOTOGRAPHED X4	
MICROSCOPIC EXAMINATION	34,656
CUT	
PICKLED	
WEIGHED	3,648
CUT	
TENSILE TESTED	6,912
TOTAL	45,216

Cotton

Analysis step	Number of Data Points
FIELD PICK UP	
PLATED FOR MICROORGANISMS	
PHOTOGRAPHED	
MICROSCOPIC EXAMINATION	8,160
TENSILE TESTED	4,608
REFLECTIVITY MEASURED	18,432
WASHED	
REFLECTIVITY MEASURED	18,432
TOTAL	49,632

Polyvinyl Chloride (PVC) and Nylon

Analysis step	PVC	Nylon
FIELD PICK UP	8,160	6,630
PLATED FOR MICROORGANISMS	8,160	6,630
PHOTOGRAPHED		
MICROSCOPIC EXAMINATION	8,160	11,934
CUT		
TENSILE TESTED	4,896	9,216
CUT		
TRANSMISSIVITY MEASURED	8,976	8,448
TOTAL	30,192	36,228

Figure 7. Analyses Flow Diagram and Number of Data Points for Exposed Samples.

(reference 5), and D638 for plastics (reference 1). Cotton strips were tested by using cross sectional samples from both ends and from the center. The material was gripped between rubber-faced steel grips. All rubber and plastic tensile specimens were cut from the strips in three locations (near the bottom, the top and the center) using a die, corresponding to ASTM specification ASTM D412, against a new masonite surface, driven by a 3-pound hammer. Tensile strength specimens were gripped in self-tightening roller grips as specified in ASTM D412. Steel specimens were cut in ½- x 6-inch strips from representative areas of the sample. These were gripped in wedge-type grips with teeth on only one side to minimize wrinkling of the material.

- Corrosion Weight Loss Measurement

Steel specimens were analyzed by corrosion weight loss according to ASTM G1-67 (reference 2). The procedure consisted of cutting selected areas of the sample into approximately 1-inch squares, and accurately measuring length and width in order to calculate area to the nearest thousandth of a square inch. The samples were then pickled in inhibited hydrochloric acid to remove the corrosion products. Samples were weighed, weights compared with those of equal areas of unexposed material, and percent weight loss calculated.

ANALYSIS

General

The experimental data in this report consist of measures of tensile strength, corrosion weight loss, and microbial coverage. These data were obtained at 17 tropic exposure sites, inclusive of the laboratory control site, on six materials at periodic intervals during four exposure phases. Tensile strength and corrosion weight loss measurements were used as measures of site severity on steel. Tensile strength and microbial coverage were employed as measures of site severity on cotton, nylon, polyvinyl chloride, latex and butyl. The statistic on which this study was based was the mean of measurements taken over the exposure periods for a material at a site. The mean measurements were used as an index for comparing and ranking, according to severity, the 17 tropic exposure sites with which this investigation is concerned.

The exposure phases differed in time of exposure depending upon the individual materials. For steel and latex, data points were measured at 1-week intervals (usually in triplicate) during four consecutive 12-week exposure phases. Also included for steel was a fifth phase, which overlapped the fourth phase, that was added during the latter part of the investigation to gain more definitive dry season data. Data points for cotton were measured at 2-week intervals throughout four overlapping 24-week exposure phases. For nylon, polyvinyl chloride and butyl, data points were measured at 4-week intervals throughout four overlapping 48-week exposure phases. The four planned exposure phases were initiated at 12-week intervals throughout the year in order to measure seasonal effects.

Results and analyses of time-decay curve fitting, and multiple correlation analyses between experimental data and climatic measurements, are published in Phase II of this methodology investigation and assigned TECOM Project No. 9 CO 009 000 005, (reference 44).

Statistical Procedures

The primary statistical analysis used to determine differences in site severity was the Duncan Multiple Range Test (DMRT) (reference 53). The DMRTs provided sensitive discriminations for grouping sites into clusters on the basis of statistical similarities among site severity mean values.

Seasonal effects were analyzed by calculating tensile strength mean values, from all sites combined, for a material for periodic points in time during an exposure phase. Trends of tensile strength across time were determined for each material for each of four seasonal phases. For each material, the four seasonal trends were compared with standard linear power, and exponential curves using least squares regression techniques. For each material, the type of curve that best fit the data of the four phases was used to test for significance of differences among the seasonal phase trends. An F-ratio was employed to determine significant differences among slopes of the curves. Because these analyses showed no significant seasonal phase effects, seasonal phase data were combined for the DMRTs in determining differences in site severity.

A set of secondary analyses were performed by analyzing the rank orders of site severity mean values. Various material/measure combinations provided 12 separate bases for ranking the sites according to severity. For each of the 12 rankings, sites were assigned ranks of 1 through 16 based on the highest to the lowest severity, respectively. One site, Gun Hill, was eliminated from the analyses of ranks because of incomplete data caused by a fire at the site. Because clusters of sites determined by the DMRTs overlapped to an appreciable extent, and because data obtained were the best information available for ordering sites according to severity (however small some of the differences between site means may be), equal site severity ranks were assigned only to sites which had equal severity means.

Rationale for specific statistical analyses and comparisons is provided in more detail at the beginning of each paragraph of results. The major conclusions of this investigation were drawn from the combined results of the DMRTs and the analyses of ranks.

SUMMARY OF RESULTS

Site, Mode, and Phase Severities Based on Tensile Strength and Corrosion Weight Loss

● Relative Site Severity among Individual Sites

Rationale and Summary Data for All Materials: Relative site severity for the 17 test sites (including control site) was determined for the six individual materials. Site severity was assigned by ranking mean tensile strengths ($\overline{TS}$) for each material according to magnitude. In addition, site severity for steel was assigned by ranking mean corrosion weight loss ($\overline{CWL}$) according to increasing percentage loss of original sample weight.

Data are presented in table 3 showing mean tensile strengths per site per material, and the corresponding standard deviations (SD). The data for steel include percent corrosion weight loss measurements with standard deviations. The means in table 3 were calculated from data points for all phases combined. In order to determine significant differences among site means for each material, a DMRT analysis was completed on the data in table 3.

TABLE 3. CORROSION WEIGHT LOSS MEANS ($\overline{CWL}$), TENSILE STRENGTH MEANS (TS), AND STANDARD DEVIATIONS (SD) OF SIX MATERIALS AT 16 FIELD SITES AND CONTROL (COMBINED PHASES)

	Material														
	Steel[3] (CWL, %)		Steel[3] (TS, kg_f)		Cotton[4] (TS, kg_f)		PVC[5] (TS, kg_f)		Nylon[5] (TS, kg_f)		Latex[3] (TS, kg_f)		Butyl[5] (TS, kg_f)	
Site Name[1]	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Flamenco–C	17.28	9.68	120.00	28.70	83.20	26.49	3.26	0.80	4.70	1.87	1.16	1.50	4.38	0.34
Galeta–C	28.66	18.22	105.00	42.10	97.10	27.63	3.70	0.87	5.19	1.49	1.03	1.15	4.35	0.35
Chiva Chiva–S	3.88	2.62	152.00	10.50	131.40	10.03	4.30	0.42	7.62	2.96	4.88	2.05	4.40	0.35
Fort Gulick–S	4.90	3.42	149.00	12.40	126.40	9.95	4.30	0.43	7.94	3.81	3.03	2.33	4.36	0.38
Coco Solo–S	3.91	2.68	151.00	14.10	111.80	23.30	4.42	0.49	12.19	5.33	6.02	2.25	4.37	0.34
Fort Clayton–F	3.00	3.16	142.00	17.70	107.50	40.51	4.21	0.50	13.72	2.68	5.71	2.24	4.28	0.39
Gamboa–F	3.40	2.65	135.00	20.00	82.90	46.98	4.40	0.40	12.29	3.75	6.64	1.74	4.29	0.35
Coco Solo–F	6.06	2.68	119.00	35.60	130.40	26.09	4.38	0.41	13.99	2.11	7.41	2.03	4.25	0.46
Fort Sherman–F	11.38	11.96	118.00	32.90	60.60	44.07	4.34	0.43	14.52	2.42	8.05	1.67	4.28	0.33
Gun Hill[2]–O	8.35	4.67	137.00	18.30							1.03	0.82		
Chiva Chiva–O	8.03	5.82	134.00	20.70	108.50	19.22	3.41	0.62	5.61	2.28	0.95	0.71	4.33	0.37
Gamboa–O	8.07	5.64	128.00	21.70	111.50	20.18	3.57	0.58	5.70	1.80	1.07	0.82	4.32	0.35
Coco Solo–O	10.17	6.30	132.00	19.30	111.60	18.50	3.63	0.69	5.52	1.77	1.00	1.08	4.32	0.38
Fort Sherman–O	11.00	7.36	134.00	19.40	106.00	22.35	3.41	0.93	5.27	1.91	1.01	1.12	[illegible]	0.40
Fort Gulick–O	13.65	8.97	121.00	26.90	100.50	20.39	3.48	0.68	5.23	2.28	1.24	1.40	4.32	0.42
Mangrove	59.18	33.02	60.00	41.00	132.50	21.90	4.27	0.46	9.99	4.44	2.68	1.94	4.23	0.63
Control	0.0	0.0	149.00	43.60	147.10	6.18	4.32	0.46	15.26	1.25	9.30	1.85	4.33	0.42

[1] C = coastal; O = open; S = shelters; F = forest.

[2] Blank data spaces represent samples lost because of fire at Gun Hill.

[3] Means calculated from weekly data points from four consecutive 12-week exposure phases.

[4] Means calculated from biweekly data points from four overlapping 24-week exposure phases.

[5] Means calculated from 4-week data points from four overlapping 48-week exposure phases.

Each table, 4 through 9, presents a rank order of sites based upon percent corrosion weight loss means ($\overline{CWL}$), table 4, and tensile strength means ($\overline{TS}$), tables 5 through 9. Each table shows differences between the means and which differences are statistically similar based upon the DMRT at the 1 percent level of significance. The vertical lines just to the right of site names show clusters of sites having means that are not statistically different by the above test. Sites within these clusters may be regarded as possessing similar severity toward a basic material, although the environmentally degrading parameters may be completely different. For the tensile strength analysis, rank 1 means most severe site and rank 17 the least severe. A DMRT analysis was not completed for butyl rubber because the variance among tensile strength means within individual sites exceeded the difference between the highest and lowest tensile strength means. Therefore, the tensile strength deterioration for butyl was not statistically significant for the exposure times used in the present study.

Site Ranks by Individual Materials: Relative site severity according to corrosion weight loss and tensile strength loss for the 16 field sites and one control site will be discussed by material, with the experimental results also shown by material.

△ Steel

Table 4 presents site ranking for mean corrosion weight loss and the results of DMRT analysis of differences between pairs of means. The ranking of 1 through 16 is for field sites only because corrosion weight loss of field-exposed samples was measured with respect to uncorroded control samples. Corrosion weight loss was least at the Fort Clayton forest site and most severe in the mangrove swamp.

Table 5 presents site ranking for steel tensile strength measurements. The ranking of sites for tensile strength is inverted. though imperfectly, from the corrosion weight loss measurements in table 4. For CWL, increasing site severity is denoted by larger numerical ranking, but for TS, greatest site severity is denoted by smaller numerical ranking.

In general, shelter sites provided the least severe environment for deterioration of steel, increasing in open sites, to the most severe at forest and coastal sites. The greatest loss in tensile strength occurred at the mangrove swamp. In table 5, Chiva Chiva open and Fort Sherman open are both ranked 9.5 because the mean tensile strengths for the two sites were equal. Fort Gulick shelter and the control site were both ranked 14.5 because their means were equal.

Since steel was the only sample material susceptible to corrosion, it was the sole indicator of site severity to detect and define tropic corrosive subenvironments for metals. Mild steel is susceptible to accelerated corrosion in the presence of various ambient factors such as excessive moisture, elevated temperatures, atmospheric salt and salt spray, and particulate matter. Nearly ideal conditions exist for corrosion of steel at several sites used in this study, as shown by the large weight-loss percentages in table 4 and the large losses in tensile strength in table 5.

The mangrove swamp, an experimental site, was the most severe for deterioration of steel. The major deterioration causing factors were unknown. Humidity and salt content in the swamp were comparable to other sites, but the deterioration rate was much greater. The obviously corrosive and strong oxidizing ambient conditons in the mangrove swamp were unique and unparalleled by other subenvironments studied during this investigation. Figure 8 shows the high rate of tensile strength loss measured in steel specimens at the mangrove site during the rainy season (Phase 2). Complete loss of tensile strength occurred within 4 weeks of exposure.

TABLE 4. SITE RANKS FOR STEEL BASED ON CORROSION WEIGHT LOSS MEANS ($\overline{CWL}$) AND SITE CLUSTERS DETERMINED BY DUNCAN'S MULTIPLE RANGE TEST ON DIFFERENCES BETWEEN PAIRS OF MEANS

Rank	Site‡	$\overline{CWL}$,%†	1 3.0	2 3.4	3 3.88	4 3.91	5 4.90	6 6.06	7 8.03	8 8.07	9 8.35	10 10.17	11 11.0	12 11.38	13 13.65	14 17.28	15 28.66	16 59.18	Duncan's Shortest Significant Ranges, α = 0.01
1	Fort Clayton–F	3.00		0.4	0.89	0.91	1.90	3.06	5.03	5.07	5.35	7.17*	8.00*	8.38*	10.85*	14.28*	25.66*	56.18*	
2	Gamboa–F	3.40			0.48	0.51	1.50	2.66	4.63	4.67	4.95	6.67*	7.60*	7.98*	10.45*	13.88*	25.26*	55.78*	R_2 = 5.57
3	Chiva Chiva–S	3.88				0.03	1.02	2.18	4.15	4.19	4.47	6.29*	7.12*	7.50*	9.97*	13.40*	24.78*	55.30*	R_3 = 5.81
4	Coco Solo–S	3.91					0.99	2.15	4.12	4.16	4.44	6.26*	7.09*	7.47*	9.[illegible]4*	13.37*	24.75*	55.21*	R_4 = 5.97
5	Fort Gulick–S	4.90						1.16	3.13	3.17	3.45	5.77	6.10*	6.48*	8.95*	12.38*	23.76*	54.28*	R_5 = 6.00
6	Coco Solo–F	6.06							1.97	2.01	2.29	4.11	4.94	5.32	7.79*	11.22*	22.60*	53.12*	R_6 = 6.18
7	Chiva Chiva–O	8.03								0.04	0.32	2.14	2.97	3.35	5.82	9.25*	20.63*	51.15*	R_7 = 6.26
8	Gamboa–O	8.07									0.28	2.10	2.93	3.31	5.78	9.21*	20.59*	51.11*	R_8 = 6.33
9	Gun Hill–O	8.35										1.82	2.65	3.03	5.50	8.93*	20.31*	50.83*	R_9 = 6.38
10	Coco Solo–O	10.17											0.83	1.21	3.68	7.11*	18.49*	49.01*	R_{10} = 6.43
11	Fort Sherman–O	11.00												0.38	2.85	6.28*	17.66	48.18	R_{11} = 6.48
12	Fort Sherman–F	11.38													2.47	5.90	17.28*	47.80*	R_{12} = 6.52
13	Fort Gulick–O	13.65														3.43	14.81*	45.33*	R_{13} = 6.56
14	Flamenco–C	17.28															11.38*	41.90*	R_{14} = 6.59
15	Galeta–C	28.66																30.52*	R_{15} = 6.62
16	Mangrove	59.18																	R_{16} = 6.65

Indicates clusters of means not significantly different from each other.

* Range is significant at the 0.01 level
† Means calculated from weekly data points from four consecutive 12-week exposure phases
Harmonic Mean Sample Size (N_h) = 53.33
Standard Error of Mean ($S_{\bar{x}}$) = 1.53
‡ C = coastal; O = open; S = shelter; F = forest

TABLE 5. SITE RANKS FOR STEEL BASED ON TENSILE STRENGTH MEANS ($\overline{TS}$) AND SITE CLUSTERS DETERMINED BY DUNCAN'S MULTIPLE RANGE TEST ON DIFFERENCES BETWEEN PAIRS OF MEANS

Rank	Site‡	$\overline{TS}$, kg_f†	1 60.0	2 105.0	3 118.0	4 119.0	5 120.0	6 121.0	7 128.0	8 132.0	9.5 134.0	11 135.0	12 137.0	13 142.0	14.5 149.0	16 151.0	17 152.0	Duncan's Shortest Significant Ranges $\alpha = 0.01$
1	Mangrove	60.0		45*	58*	59*	60*	61*	68*	72*	74*	75*	77*	82*	89*	91*	92*	
2	Galeta-C	105.0			13*	14*	15*	16*	23*	27*	29*	30*	32*	37*	44*	44*	47*	R_2 = 6.92
3	Ft Sherman-F	118.0				1	2	3	10*	14*	16*	17*	19*	24*	31*	33*	34*	R_3 = 7.21
4	Coco Solo-F	119.0					1	2	9*	13*	15*	16*	18*	23*	30*	32*	33*	R_4 = 7.41
5	Flamenco-C	120.0						1	8*	12*	14*	15*	17*	22*	29*	31*	32*	R_5 = 7.56
6	Ft Gulick-O	121.0							7*	11*	13*	14*	16*	21*	28*	30*	31*	R_6 = 7.68
7	Gamboa-O	128.0								4	6	7	9*	14*	21*	23*	24*	R_7 = 7.77
8	Coco Solo-O	132.0									2	3	5	10*	17*	19*	20*	R_8 = 7.86
9.5	Chiva Chiva-O	134.0										1	3	8*	15*	17*	18*	$R_{9.5}$ = 7.93
9.5	Ft Sherman-O																	
11	Gamboa-F	135.0											2	7	14*	16*	17*	R_{11} = 7.99
12	Gun Hill-O	137.0												5	12*	14*	15*	R_{12} = 8.05
13	Ft Clayton-F	142.0													7	9*	10*	R_{13} = 8.10
14.5	Ft Gulick-S	149.0														2	3	$R_{14.5}$ = 8.14
14.5	Control																	
16	Coco Solo-S	151.0															1	R_{16} = 8.18
17	Chiva Chiva-S	152.0																R_{17} = 8.22

Indicates clusters of means not significantly different from each other.

*Range is significant at the 0.01 level

†Means calculated from weekly data points from four consecutive 12-week exposure phases

Harmonic Mean Sample Size (N_h) = 211.9

Standard Error of Mean ($S_{\bar{x}}$) = 1.9

‡C = coastal; O = open; S = shelter; F = forest

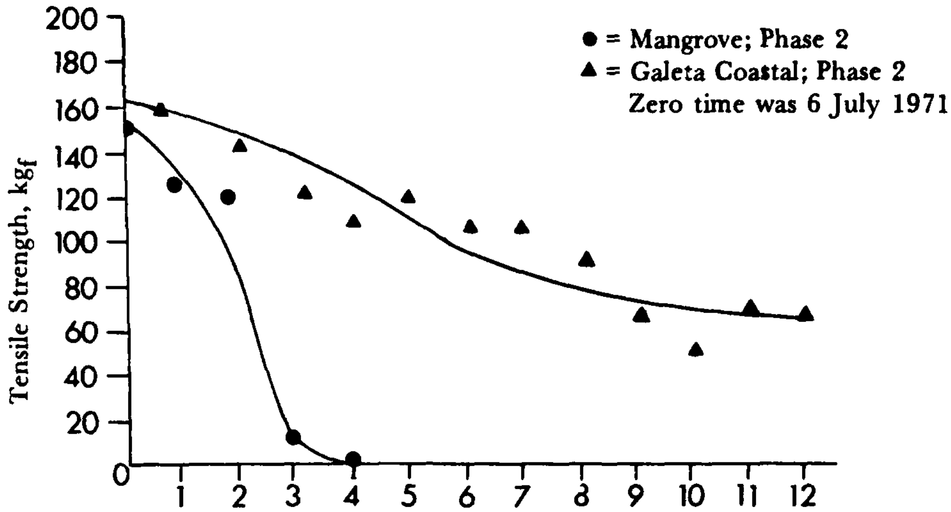

Figure 8. Tensile Strength Loss of Steel in Phase 2 of Exposure

The second most severe site for steel was Galeta coastal. Tensile strength data measured for that site during Phase 2 of exposure are also presented in figure 8. After 12 weeks of exposure, steel specimens still retained approximately 37 percent of their original tensile strength. This may be compared with specimens at the mangrove site which lost 100 percent of their tensile strength within 4 weeks. The reason for the Galeta coastal site being the second most severe toward steel was the large ambient salt concentration (table C-2) and moisture. An almost continuous salt spray from the Caribbean sea was incident on the samples, thus enhancing deterioration of steel at this site. Salt concentration was considerably higher at Galeta than at Flamenco, the other coastal site.

Fort Sherman forest, Coco Solo forest, Flamenco coastal and Fort Gulick open sites were statistically equivalent in severity as seen in table 5. This grouping encompasses sites where a combination of environmental conditions produced the corrosion rather than one predominant factor, as was indicated at the Galeta coastal site. The forest sites were characterized by warm humid conditions where oxidation of the steel easily occurred. Flamenco coastal and Fort Gulick open were characterized by higher concentrations of salt fall. The Flamenco coastal site was the only site within this equivalent cluster which was located on the Pacific side of the Isthmus.

The remaining sites provided a severity ranking commensurate with the relative corrosiveness of their subenvironments. Again, the corrosion which occurred at the remaining sites was most likely a combination of individual effects such as moisture, salt, warm temperature, and other corrosive parameters.

The Galeta coastal site, on the Atlantic coast, ranked 2 for steel and was more severe and statistically different in severity from the Flamenco site, ranked 5, on the Pacific coast.

The Fort Sherman and Coco Solo forest sites, both located on the Atlantic side of the Isthmus, ranked 3 and 4, and were greater in severity toward steel than the forest sites at Gamboa (ranked 11; mid-Isthmus) and Fort Clayton (ranked 13; Pacific).

The open sites were generally comparable in severity whether on the Atlantic or Pacific side or at mid-Isthmus. The sheltered sites were also similar in severity independent of location.

As may be seen in table 5, the Fort Gulick, Coco Solo and Chiva Chiva shelter sites and the Fort Clayton forest site were not statistically different in tensile-strength loss from the control site. The tensile strengths of the steel samples at these shelter sites were equivalent to those experienced inside the air-conditioned laboratory storage room where control samples were exposed. In terms of corrosion weight loss however, all four sites were significantly more severe than controls.

△ Cotton

Site ranking for cotton according to tensile strength is presented in table 6. The most severe site for cotton was Fort Sherman forest. (Gun Hill open site was not included in the rankings because part of the samples were destroyed by fire, resulting in incomplete data.)

In general, forest sites were most severe, followed by coastal and open, with sheds and mangrove being least severe. Solar radiation is usually considered the most degrading nonbiological environmental factor for textiles. The destructive power of sunlight is dependent upon geographical location, atmospheric conditions, number of daylight hours, and other factors such as type of cover and protection from the environment. Also, environmental factors such as moisture, oxygen and ozone can result in nonbiological deterioration of cellulose-base material. In a tropical climate, the single most degrading force from any cause is considered to be attack by cellulolytic enzymes from microorganisms. The enzymes attack the fiber structure of the cotton. The large amount of fungus coverage experienced at Fort Sherman forest site (table 15) indicated that this may be the deterioration mechanism which made this site the most severe for tensile strength loss in cotton. Also, it may be the predominant reason for Gamboa forest being the next most severe site.

While the Fort Sherman forest and Gamboa forest sites were ranked 1 and 2, respectively, they were statistically different in severity. Also, they were both statistically different from the Fort Clayton forest (Pacific side) and the Coco Solo forest (Atlantic side). Both of these latter sites were considerably less severe than the Fort Sherman and Gamboa forests.

As may be seen from table 6, there was no significant difference between the severity at the Gamboa forest site and the Flamenco coastal site. The deterioration mechanism at these two sites should have been different; the Gamboa forest site was characterized by abundant fungal coverage and the Flamenco site was characterized by high solar radiation. The insignificant statistical difference between the two sites indicated similar losses in tensile strength resulting from two different mechanisms. The Gamboa forest and Flamenco coastal were both experimental sites.

TABLE 6. SITE RANKS FOR COTTON BASED ON TENSILE STRENGTH MEANS ($\overline{TS}$) AND SITE CLUSTERS DETERMINED BY DUNCAN'S MULTIPLE RANGE TEST ON DIFFERENCES BETWEEN PAIRS OF MEANS

Rank	Site‡	$\overline{TS}$, kg_f†	1 60.6	2 82.9	3 83.2	4 97.1	5 100.5	6 106.0	7 107.5	8 108.5	9 111.5	10 111.6	11 111.8	12 126.4	13 130.4	14 131.4	15 132.5	16 147.1	Duncan's Shortest Significant Ranges, α = 0.01
1	Fort Sherman–F	60.6		22.3*	22.6*	36.5*	59.9*	45.4*	46.9*	47.9*	50.9	51.0*	51.2*	65.8*	69.8*	70.8*	71.9*	86.5*	
2	Gamboa–F	82.9			0.3	14.2*	17.6*	23.1*	24.6*	25.6*	28.6*	28.7*	28.9*	43.5*	47.5*	48.5*	49.6*	64.2*	R_2 = 8.27
3	Flamenco–C	83.2				14.9*	17.3*	22.8*	24.3*	25.3*	28.3*	28.4*	28.6*	43.2*	47.2*	48.2*	49.3*	63.9*	R_3 = 8.62
4	Galeta–C	97.1					3.4	8.9*	10.4*	11.4*	14.4*	14.5*	14.7*	29.3*	33.3*	34.3*	35.4*	50.0*	R_4 = 8.85
5	Fort Gulick–O	100.5						5.5	7.0	8.0	11.0*	11.1*	11.3*	25.9*	29.9*	30.9*	32.0*	46.6*	R_5 = 9.03
6	Fort Sherman–O	106.0							1.5	2.5	5.5	5.6	5.8	20.4*	24.4	25.4*	26.5*	41.1*	R_6 = 9.17
7	Fort Clayton–F	107.5								1.0	4.0	4.1	4.3	18.9*	22.9*	23.9*	25.0*	39.6*	R_7 = 9.28
8	Chiva Chiva–O	108.5									3.0	3.1	3.3	17.9*	21.9*	22.9*	24.0*	38.6*	R_8 = 9.39
9	Gamboa–O	111.5										0.1	0.3	14.9*	18.9*	19.9*	21.0*	35.6*	R_9 = 9.47
10	Coco Solo–O	111.6											0.2	14.8*	18.8*	19.8*	20.9*	35.5*	R_{10} = 9.54
11	Coco Solo–S	111.8												14.6*	18.6*	19.6*	20.7*	35.3*	R_{11} = 9.61
12	Fort Gulick–S	126.4													4.0	5.0	6.1	20.7*	R_{12} = 9.67
13	Coco Solo–F	130.4														1.0	2.1	16.7*	R_{13} = 9.73
14	Chiva Chiva–S	131.4															1.1	15.7*	R_{14} = 9.78
15	Mangrove	132.5																14.6*	R_{15} = 9.82
16	Control	147.1																	R_{16} = 9.86

Indicates clusters of means not significantly different from each other.

* Range is significant at the 0.01 level.
† Means calculated from biweekly data points from four overlapping 24-week phases
Harmonic Mean Sample Size (N_h) = 138.3
Standard Error of Mean ($S_{\bar{x}}$) = 2.27
‡ C = coastal; O = open; S = shelter; F = forest

The Galeta coastal site and Fort Gulick open site were not statistically different in severity. Their similarity existed because both were open sites where incident solar radiation was high. This primary environmental factor placed these sites fourth and fifth in the severity ranking.

The severity of the remaining sites proceeded according to protection afforded—sites without protection from solar radiation being more severe than sites protected by sheds. The incident ultraviolet radiation at open sites caused more severe degradation of cotton than that found under sheds. The sheds did not provide as favorable a condition for fungal growth as did the humid forest sites, therefore they were the least severe sites for cotton.

The mangrove swamp does not provide optimum conditions for fungal growth. The warm humid environment is characterized by relatively high salt fall with moderate sunlight penetrating through the jungle canopy. These two factors, combined with the extremely corrosive environment, retard most fungal activity and provide a relatively protected environment for textiles.

In general, the open sites were statistically similar in severity irrespective of geographical location. For the sheltered sites, Coco Solo was more severe than the Fort Gulick and Chiva Chiva sites. All sites were more severe than the control site for cotton.

△ Nylon

Table 7 contains the tensile strength data for nylon. Sites ranked 1 through 7 composed a statistically equivalent cluster with respect to severity. The primary environmental factor common to all of these sites is sunlight, with ultraviolet rays being the primary damaging component.

The most severe site, Flamenco coastal, was an experimental site and is located on the Pacific side of the Isthmus. Also, within this statistically equivalent cluster of sites, the Coco Solo open (Pacific side) and Gamboa open were experimental sites. Gamboa open site is located at mid-Isthmus.

The sheltered sites provide protection for nylon from primary (direct) ultraviolet radiation, but samples are still susceptible to secondary radiation. Secondary radiation reaches the samples by reflection or indirect means. This condition, of being intermediate between open and forest sites, placed the severity of the shed sites between those two modes of exposure. The two most severe shelter sites were at Chiva Chiva (ranked 8) and Fort Gulick (ranked 9). These two sites were statistically similar and were located on opposite sides of the Isthmus—Chiva Chiva on the Pacific side and Fort Gulick on the Atlantic side.

The mangrove swamp (ranked 10) was approximately midway in severity of all sites considered and was statistically different from all other sites. The strong oxidizing agents encountered in the mangrove swamp may have contributed to deterioration of the nylon polymers. Also, the small amount of solar radiation that penetrated the mangrove canopy could have played a minor role in the performance of nylon. Because moisture absorption by nylon is low, the high relative humidity encountered in the swamp resulted in negligible deterioration.

TABLE 7. SITE RANKS FOR NYLON BASED ON TENSILE STRENGTH MEANS ($\overline{TS}$) AND SITE CLUSTERS DETERMINED BY DUNCAN'S MULTIPLE RANGE TEST ON DIFFERENCES BETWEEN PAIRS OF MEANS

Rank	Site‡	$\overline{TS}$, kg_f†	1 4.7	2.5 5.2	4 5.3	5 5.5	6 5.6	7 5.7	8 7.6	9 7.9	10 10.0	11 12.2	12 12.3	13 13.7	14 14.0	15 14.5	16 15.3	Duncan's Shortest Significant Ranges α = 0.01
1	Flamenco-C	4.7		0.5	0.6	0.8	0.9	1.0	2.9*	3.2*	5.3*	7.5*	7.6*	9.0*	9.3*	9.8*	10.6*	
2.5	Galeta-C	5.2			0.1	0.3	0.4	0.5	2.4*	2.7*	4.8*	7.0*	7.1*	8.5*	8.8*	9.3*	10.1*	$R_{2.5}$ = 9.73
2.5	Ft Gulick-O																	
4	Ft Sherman-O	5.3				0.2	0.3	0.4	2.3*	2.6*	4.7*	6.9*	7.0*	8.4*	8.7*	9.2*	10.1*	R_4 = 10.14
5	Coco Solo-O	5.5					0.1	0.2	2.2*	2.4*	4.5*	6.7*	6.8*	8.2*	8.5*	9.0*	9.8*	R_5 = 10.41
6	Chiva Chiva-O	5.6						0.1	2.0*	2.3*	4.4*	6.6*	6.7*	8.1*	8.4*	8.9*	9.7*	R_6 = 10.62
7	Gamboa-O	5.7							1.9*	2.2*	4.3*	6.5*	6.6*	8.0*	8.3*	8.8*	9.6*	R_7 = 10.78
8	Chiva Chiva-S	7.6								0.3	2.4*	4.6*	4.7*	6.1*	6.4*	6.9*	7.7*	R_8 = 10.92
9	Ft Gulick-S	7.9									2.1*	4.3*	4.4*	5.8*	6.1*	6.6*	7.4*	R_9 = 11.04
10	Mangrove	10.0										2.2*	2.3*	3.7*	4.0*	4.5*	5.3*	R_{10} = 11.14
11	Coco Solo-S	12.2											0.1	1.5*	1.8*	2.3*	3.1*	R_{11} = 11.23
12	Gamboa-F	12.3												1.4*	1.7*	2.2*	3.0*	R_{12} = 11.31
13	Ft Clayton-F	13.7													0.3	0.8	1.5*	R_{13} = 11.38
14	Coco Solo-F	14.0														0.5	1.3*	R_{14} = 11.44
15	Ft Sherman-F	14.5															0.8	R_{15} = 11.50
16	Control	15.3																R_{16} = 11.55

Indicates clusters of means not significantly different from each other.

*Range is significant at the 0.01 level

†Means calculated from 4-week data points from four overlapping 48-week exposure phases

Harmonic Mean Sample Size (N_h) = 106.0

Standard Error of Means ($S_{\bar{x}}$) = 0.267

‡C = coastal; O = open; S = shelter; F = forest

Deterioration of nylon at the forest sites was generally small compared with the open and shed sites. For example, the Fort Sherman forest site was no more severe than an air-conditioned, darkened, inside storage room. Since microbial attack on nylon is not usually encountered and moisture absorption is small, the most intense environmental effects encountered under the jungle canopy caused only minor loss of nylon tensile strength. For the forest sites, Gamboa (mid-Isthmus, ranked 12) was the most severe and was statistically different from the remaining forest sites which were all similar in severity.

Δ Polyvinyl chloride (PVC)

The data for polyvinyl chloride are presented in table 8. In general, open sites, including coastal, are most severe, followed by sheds and forests.

Plasticized PVC can be degraded by ultraviolet light, heat, ozone, and sometimes by microorganisms which utilize the plasticizers, additives and fillers, but not the vinyl chloride polymer itself. During this investigation, fungal growth was usually abundant on samples exposed in dark and shady locations, especially if the area was warm and humid. In open solar radiation and exposure, deterioration initiated as stiffening and warping, then proceeded to discoloration accompanied by loss in strength. Finally, bubbling and pitting became evident in the polyvinyl chloride.

Flamenco coastal, an experimental site, was the most severe site for polyvinyl chloride. Table 8 shows that sites ranked 1 through 7 were all open or coastal sites, characterized by high levels of incident solar radiation, without natural or man-made protection to reduce the radiation intensity. Therefore, the primary degrading environmental factor for PVC in the tropics must have been ultraviolet radiation. The reason that the Flamenco coastal site, located on the Pacific coast, was more severe than the Atlantic coastal and open sites was not understood. The total solar radiation measurements were greater at the Atlantic open and coastal sites, therefore those sites were expected to be more severe. This indicated ultraviolet radiation was not the only environmental factor causing loss of tensile strength in PVC, although it was expected to be the primary one.

The Fort Sherman open, Chiva Chiva open, and Fort Gulick open sites were ranked 2, 3 and 4, respectively. These sites were statistically equivalent in severity toward PVC as were those ranking 5, 6 and 7. Relative severities of these sites were attributed to the different intensities of incident radiation.

For the open sites, Fort Sherman, Chiva Chiva and Fort Gulick sites were statistically similar in severity and more severe than the Gamboa open and Coco Solo open which were also similar. Of the three most severe open sites, only Chiva Chiva was located on the Pacific side of the Isthmus.

Sites ranked 8 through 16 showed no significant statistical difference in severity. Only small percentages of tensile strength were lost in PVC at the shed and forest sites because of the elimination of incident radiation. Although abundant fungal activity was present

TABLE 8. SITE RANKS FOR POLYVINYL CHLORIDE BASED ON TENSILE STRENGTH MEANS ($\overline{TS}$) AND SITE CLUSTERS DETERMINED BY DUNCAN'S MULTIPLE RANGE TEST ON DIFFERENCES BETWEEN PAIRS OF MEANS

Rank	Site‡	$\overline{TS}$, kg_f†	1 3.26	2 3.41	3 3.41	4 3.48	5 3.57	6 3.63	7 3.70	8 4.21	9 4.27	10 4.30	11 4.30	12 4.32	13 4.34	14 4.38	15 4.39	16 4.42	Duncan's Shortest Significant Ranges, α = 0.01
1	Flamenco–C	3.26		0.15*	0.15*	0.22*	0.31*	0.38*	0.45*	0.96*	1.01*	1.04*	1.04*	1.06*	1.08*	1.13*	1.15*	1.16*	
2	Fort Sherman–O	3.41			0.00	0.07	0.16*	0.23*	0.30*	0.81*	0.86*	0.88*	0.89*	0.91*	0.93*	0.98*	0.99*	1.01*	R_2 = 1.82
3	Chiva Chiva–O	3.41				0.07	0.16*	0.22*	0.29*	0.80*	0.86*	0.88*	0.89*	0.91*	0.93*	0.97*	0.98*	1.01*	R_3 = 1.90
4	Fort Gulick–O	3.48					0.09	0.16*	0.22*	0.73*	0.79*	0.82*	0.82*	0.84*	0.86*	0.91*	0.92*	0.94*	R_4 = 1.95
5	Gamboa–O	3.57						0.07	0.14	0.65*	0.70*	0.73*	0.73*	0.75*	0.77*	0.82*	0.83*	0.85*	R_5 = 1.99
6	Coco Solo–O	3.63							0.07	0.58*	0.63*	0.66*	0.66*	0.68*	0.70*	0.75*	0.76*	0.78*	R_6 = 2.02
7	Galeta–C	3.70								0.51*	0.56*	0.59*	0.59*	0.62*	0.63*	0.68*	0.69*	0.71*	R_7 = 2.05
8	Fort Clayton–F	4.21									0.05	0.08	0.08	0.11	0.12	0.17*	0.18*	0.20*	R_8 = 2.08
9	Mangrove	4.27										0.02	0.03	0.05	0.07	0.12	0.13	0.15	R_9 = 2.10
10	Fort Gulick–S	4.30											0.00	0.02	0.05	0.09	0.10	0.12	R_{10} = 2.11
11	Chiva Chiva–S	4.30												0.02	0.04	0.09	0.10	0.12	R_{11} = 2.13
12	Control	4.32													0.02	0.06	0.07	0.10	R_{12} = 2.14
13	Fort Sherman–F	4.34														0.05	0.06	0.08	R_{13} = 2.15
14	Coco Solo–F	4.38															0.01	0.03	R_{14} = 2.16
15	Gamboa–F	4.39																0.02	R_{15} = 2.17
16	Coco Solo–S	4.42																	R_{16} = 2.18

Indicates clusters of means not significantly different from each other.

* Range is significant at the 0.01 level

†Means calculated from 4-week data points from four overlapping 48-week exposure phases

Harmonic Mean Sample Size (N_h) = 14.11

Standard Error of Mean ($S_{\bar{x}}$) = 0.05

‡C = coastal; O = open; S = shelter; F = forest

on PVC samples collected from the forest sites, biodeterioration did not appear to be a primary cause of tensile strength loss. The sites ranked 8 through 15 were not statistically different in severity from the control site, ranked 12. The sites ranked 13 through 16, Coco Solo forest and shelter, and Gamboa forest, offered a slightly more benign exposure environment than the air-conditioned control site. However, the difference was not statistically significant.

△ Latex Rubber

Table 9 presents the ranking for all sites for latex. In general, open sites, to include coastal, are the most severe—sites protected from sunlight, to include sheds and forests, are less severe.

Natural rubber is very susceptible to environmental degradation. Solar radiation, ozone, heat, oils, moisture, chemical agents and microbiological agents all degrade latex. Degradation processes are not usually separated into photochemical, thermal, oxidative or microbiological factors, but are grouped as cumulative effects. For many rubber materials the actual degradation is a function of fillers, stabilizers and other materials compounded into the rubber during manufacture of an end item. When microbiological degradation occurs on rubber, it is often more dependent upon these additives and not the basic rubber molecule. Also in many cases, actinic degradation is a prerequisite to making rubber susceptible to microbiological deterioration.

As may be seen from table 9, the open and coastal sites were most severe for latex rubber, ranking 1 through 8. This again indicated ultraviolet radiation was the primary degradative environmental parameter for latex in the tropics. Within these eight sites, Chiva Chiva, Coco Solo open, Gun Hill open, Gamboa open, and Flamenco coastal were all experimental sites. Chiva Chiva, Gun Hill and Flamenco were located on the Pacific side of the Isthmus.

The mangrove swamp and Fort Gulick shelter site were ranked 9 and 10; they were not statistically different in severity. The mangrove canopy was not as dense as in the forest and did not provide as complete solar radiation protection as the other forest sites.

For the sheltered sites, Fort Gulick on the Atlantic side was the most severe, with a ranking of 10. Its severity was statistically different from the other shelter sites at Chiva Chiva (Pacific side, ranked 11) and Coco Solo (Atlantic side, ranked 13). It is possible that a greater amount of solar radiation reached the samples in the Fort Gulick shed because of its having a higher roof than that of other shed sites.

All of the forest sites were statistically different in severity from each other, with the Fort Clayton site (Pacific side, ranked 12) being most severe. The Gamboa site (ranked 14) was the next most severe forest site followed by the Atlantic sites at Coco Solo and Fort Sherman forests. All sites were significantly more severe than the control.

TABLE 9. SITE RANKS FOR LATEX BASED ON TENSILE STRENGTH MEANS ($\overline{TS}$) AND SITE CLUSTERS DETERMINED BY DUNCAN'S MULTIPLE RANGE TEST ON DIFFERENCES BETWEEN PAIRS OF MEANS

Rank	Site‡	$\overline{TS}$,kg_f†	1 0.95	2 0.99	3 1.01	4 1.03	5 1.03	6 1.06	7 1.16	8 1.24	9 2.68	10 3.03	11 4.88	12 5.71	13 6.02	14 6.64	15 7.40	16 8.05	17 9.30	Duncan's Shortest Significant Ranges α = 0.01
1	Chiva Chiva-O	0.95		0.04	0.06	0.08	0.08	0.12	0.22	0.29	1.73*	2.08*	3.93*	4.76*	5.07*	5.69*	6.46*	7.10*	8.35*	
2	Coco Solo-O	0.99			0.01	0.04	0.04	0.07	0.17	0.24	1.69*	2.03*	3.88*	4.72*	5.02*	5.65*	6.41*	7.06*	8.31*	R_2 = 5.10
3	Ft Sherman-O	1.01				0.02	0.02	0.06	0.16	0.23	1.67*	2.02*	3.87*	4.70*	5.01*	5.63*	6.40*	7.04*	8.29*	R_3 = 5.31
4	Gun Hill-O	1.03					0.00	0.04	0.14	0.21	1.65*	2.00*	3.85*	4.68*	4.99*	5.61*	6.38*	7.02*	8.27*	R_4 = 5.46
5	Galeta-C	1.03						0.03	0.13	0.21	1.65*	2.00*	3.85*	4.68*	4.99*	5.61*	6.37*	7.02*	8.27*	R_5 = 5.57
6	Gamboa-O	1.06							0.10	0.17	1.61*	1.96*	3.81*	4.65*	4.95*	5.54*	6.34*	6.99*	8.23*	R_6 = 5.66
7	Flamenco-C	1.16								0.07	1.51*	1.86*	3.71*	4.55*	4.85*	5.44*	6.24*	6.89*	8.13*	R_7 = 5.73
8	Ft Gulick-O	1.24									1.44*	1.79*	3.64*	4.47*	4.78*	5.40*	6.17*	6.81*	8.06*	R_8 = 5.79
9	Mangrove	2.68										0.35	2.20*	3.03*	3.34*	3.96*	4.72*	5.37*	6.62*	R_9 = 5.84
10	Ft Gulick	3.03											1.85*	2.68*	2.99*	3.61*	4.38*	5.02*	6.27*	R_{10} = 5.89
11	Chiva Chiva-S	4.88												0.83*	1.14*	1.76*	2.53*	3.17*	4.42*	R_{11} = 5.93
12	Ft Clayton-F	5.71													0.31	0.93*	1.69*	2.34*	3.59*	R_{12} = 5.97
13	Coco Solo-S	6.02														0.62*	1.39*	2.03*	3.28*	R_{13} = 6.00
14	Gamboa-F	6.64															0.77*	1.41*	2.66*	R_{14} = 6.03
15	Coco Solo-F	7.40																0.65*	1.89*	R_{15} = 6.06
16	Ft Sherman-F	8.05																	1.25*	R_{16} = 6.08
17	Control	9.30																		R_{17} = 6.11

Indicates clusters of means not significantly different from each other.

* Range is significant at the 0.01 level

†Means calculated from weekly data points from four consecutive 42-week exposure phases

Harmonic Mean Sample Size (N_h) = 138.6

Standard Error of the Means ($S_{\bar{x}}$) = 1.40

‡C = coastal; O = open; S = sheltered; F = forest

△ Butyl

Butyl rubber did not lose a measureable amount of tensile strength during the time period for which it was exposed. Consequently, site severity comparisons based on tensile strength measurements were not definitive.

● Severity of Exposure Modes

Rationale for Grouping Sites into Exposure Modes: Severity differences within environmentally similar exposure modes were evaluated. These analyses were completed to detect general severity trends among the open, coastal, shelter, forest and mangrove modes. The open modes were at Chiva Chiva, Fort Gulick and Fort Sherman (Gun Hill open data were included where available); coastal modes consisted of Galeta and Flamenco; shelter modes were located at Chiva Chiva, Fort Gulick and Coco Solo; and forest sites at Fort Clayton, Gamboa, Coco Solo and Fort Sherman. Only one mangrove site was used at Coco Solo.

The differing modes of exposure were selected to provide information on site severity for as many tropic subenvironments as possible. All modes utilized only natural surroundings, except the shelter modes which used an open-sided shed for artificial protection from rain and solar radiation. In most cases, test sites were in geographic proximity but the mode of exposure differed. For example, groups of sites in geographic proximity were: Gamboa forest and open sites; Coco Solo open, shelter and forest sites; and Fort Clayton forest, Chiva Chiva shelter, Gun Hill open and Flamenco coastal.

Table 10 provides an empirical check of the *a priori* rationale used to devise the exposure modes. If all test sites within a mode were equally severe on a material, then analysis of variance of tensile strength means within a mode would produce an F-ratio close to 1.0 (statistically nonsignificant main effect for sites within a mode). Table 10 shows the results of 24 such analyses of variance (four modes, six materials). Ten of the 24 analyses showed no difference among site means for an exposure mode (the .01 level of statistical significance is used throughout this report). Therefore, the rationale for developing the modes demonstrates a reasonable amount of empirical validity. However, it should be noted that none of the modes is completely free of differences between sites for all materials; and it should be emphasized that the data in table 11 provide information on general severity trends among modes and ignore the individual site differences indicated in table 10.

TABLE 10. F-SCORES (F_c) FOR DIFFERENCES AMONG SITES WITHIN EXPOSURE MODES BY MATERIAL

Exposure Mode	F-ratios*					
	Steel	Cotton	Nylon	Latex	Butyl	PVC
Open	15.20†	48.10†	1.30	1.80‡	1.90	3.10
Coastal	30.90†	21.20†	5.20	0.70	0.50	28.10†
Shelter	4.50	7.70†	43.70†	73.10†	1.20	14.70†
Forest	71.40†	68.70†	19.70†	56.60†	0.50	13.80†

*Mangrove site omitted because data were available from one site only
†Indicates significance at the 0.01 level
‡ Includes Gun Hill site data

TABLE 11. TENSILE STRENGTH MEANS ($\overline{TS}$) AND STANDARD DEVIATIONS (SD) FOR MATERIALS WITHIN EXPOSURE MODES

Exposure Mode	Steel* $\overline{TS}$, kg_f	Steel* SD	Cotton† $\overline{TS}$, kg_f	Cotton† SD	Nylon‡ $\overline{TS}$, kg_f	Nylon‡ SD	Latex* $\overline{TS}$, kg_f	Latex* SD	Butyl‡ $\overline{TS}$, kg_f	Butyl‡ SD	PVC‡ $\overline{TS}$, kg_f	PVC‡ SD
Open	131.00	21.80	107.60	21.40	5.12	2.02	1.05	1.02	4.33	0.38	3.50	0.71
Coastal	105.00	37.00	90.20	27.91	4.95	1.71	1.10	1.33	4.38	0.36	3.48	0.44
Shelter	151.00	12.00	123.20	17.76	9.25	1.71	4.64	2.53	4.37	0.32	4.33	0.87
Forest	130.00	27.70	95.30	47.91	13.63	2.92	6.95	2.11	4.28	0.39	4.33	0.44
Mangrove	60.00	41.00	132.50	21.90	10.00	1.25	2.68	1.94	4.23	0.63	4.27	0.46

Tensile Strength

*Means calculated from weekly data points from four consecutive 12-week exposure phases
†Means calculated from biweekly data points from four overlapping 24-week exposure phases
‡Means calculated from 4-week data points from four overlapping 48-week exposure phases

Exposure Mode Severity for Specific Materials:

△ Steel

Based on the tensile strength means in table 11, the most severe exposure mode for steel was the mangrove swamp followed by the coastal, forest, and open, and finally the shelter modes. The mangrove mode consisted of only one exposure site and is presented in table 11 because of its uniquely different environmental severity from the other modes of exposure. The shelter mode was the only mode which was internally equivalent in severity with respect to steel.

△ Cotton

For cotton, the most severe combined exposure mode was the coastal sites followed closely by the forest sites. These two types were followed in severity by the open and sheltered sites, respectively, with the mangrove swamp displaying least severity.

△ Nylon

Degradation of nylon was very similar at the open and coastal sites, as indicated by their tensile strength means which are of similar magnitude. The above more severe modes were followed in severity by the sheltered, mangrove and forest modes, respectively. The open and coastal modes were each internally equivalent in severity with respect to nylon.

△ Polyvinyl chloride

For polyvinyl chloride, the coastal and open sites were the most severe and the tensile strength means were approximately equal. Also, the remaining three modes of exposure, the shelter, forest and mangrove, were essentially the same in severity according to this analysis. The open mode of exposure was internally equivalent in severity with respect to polyvinyl chloride.

△ Latex

Results for latex were very similar to those for nylon. The open and coastal sites were the most severe and their tensile strength means were nearly equal. The mangrove swamp was the next most severe mode of exposure and it was followed by the shelter and forest modes. As for nylon, the open and coastal modes were internally equivalent in severity with respect to latex.

△ Butyl

The tensile strength means for butyl rubber are essentially the same for all of the combined exposure modes. Differences in severity cannot be detected from this analysis.

● Severity of Phases (Seasonal Effects)

Rationale for Phases: Four phases of sample exposure were used to evaluate site severity during seasonal changes in the tropics. This was completed to determine the effects of tropic wet and dry seasons on deterioration. It was also designed to isolate optimum short time exposure periods which would provide guidelines for accelerated test periods.

The phases for sample placement of material specimens at the 16 field exposure sites and one control were: Phase 1 beginning 6 April 1971 and corresponding to the late dry season; Phase 2, 6 July 1971, corresponding to the early rainy season; Phase 3, 27 September 1971, corresponding to late rainy season; and Phase 4, 20 December 1971, corresponding to early dry season. An additional exposure period for steel specimens only was initiated 7 February 1972 and corresponded to the dry season.

Phase Severity: Table 12 summarizes results of the phase analysis for each material per phase. It also shows the F-ratio for acceptability of the null hypothesis for phase comparisons. The null hypothesis was that phase slopes of the regression equations for each material were equal; the computed F-score must have been greater than the critical F-score for the hypothesis to be rejected.

For steel, latex, nylon, polyvinyl chloride and cotton, the null hypothesis was not rejected therefore no significant phase effects were found. An analysis for butyl was not completed because correlation coefficients were not significantly different from zero. No phase effects were possible because no significant deterioration occurred.

The question of phase effects was not settled by this experiment. The design may have been too gross to detect the effects. In the Optimum Sites Phase II report (reference 44), some evidence of sequence and phase effects is reported. However, it was necessary to statistically hold constant certain weather parameters, which was not true of the present study.

TABLE 12. SUMMARY OF REGRESSION EQUATIONS FOR TENSILE STRENGTH AS A FUNCTION OF EXPOSURE TIME, CORRELATION COEFFICIENT, AND F-RATIOS FOR FIELD EXPOSURE PHASES

Type Material	Phase Number	Regression Equation	Correlation† Coefficient	F-Ratio‡
Steel	1	y = 149.1exp(-0.0037t)	-.93	0.1
	2	y = 159.8exp(-0.0054t)	-.96	
	3	y = 157.0exp(-0.0036t)	-.96	
	4	y = 150.1exp(-0.0044t)	-.93	
	5*	y = 165.0exp(-0.0062t)	-.98	
Latex	1	y = 6.36exp(-0.134t)	-.88	1.0
	2	y = 6.63exp(-0.115t)	-.87	
	3	y = 6.39exp(-0.01502t)	-.78	
	4	y = 6.02exp(-0.01752t)	-.91	
Cotton	1	y = 151.63 - 0.372t	-.97	3.8
	2	y = 125.02 - 0.305t	-.98	
	3	y = 142.89 - 0.361t	-.99	
	4	y = 143.09 - 0.363t	-.98	
Polyvinyl Chloride	1	y = 4.34 - 0.0024t	-.86	3.8
	2	y = 4.47 - 0.0032t	-.91	
	3	y = 4.49 - 0.0037t	-.92	
	4	y = 4.49 - 0.0011t	-.46	
Nylon	1	y = 13.15 - 0.0232t	-.95	0.4
	2	y = 3.32 - 0.0229t	-.92	
	3	y = 12.68 - 0.0170t	-.88	

*Exposure period beginning 7 February 1972 to insure dry season exposure for steel
†Correlation of means
‡There are no significant differences in slopes for $\alpha = 0.01$

Relative Site Severity Based on Microbiological Observations

- Rationale for Microbiological Observations

Abundant microbiological growth has always been one of the major degrading environmental parameters in the tropics. Therefore, data were collected to assess site severity based on fungus coverage for each material, except steel, at each exposure site. Also, additional background microbiological measurements were made at each site by air and soil sampling techniques. These background data are found in table 1.

To assign site severity, microbial coverage on the test specimens was given a numerical rating corresponding to the percent of specimen area covered. The rating codes were consistent with the WSMR Microbial Test Evaluation Scheme, table C-3. Relative site severities were actually determined by ranking mean grades according to increasing magnitude for individual materials and all materials combined. Unlike tensile strength rankings in the preceding sections, rank 1 in microbial coverage, Duncan's Multiple Range analyses mean least severity.

Test sites were grouped also into clusters whose members exhibited similar severity of fungus coverage. The clusters were determined by completing a DMRT at the 1 percent level of significance on differences between pairs of mean grades. Equivalent clusters were determined for each material separately (tables 13 through 17) and for all materials combined (table 18).

In performing an analysis of individual test sites based on microbiological measurements, it was necessary to consider many environmental parameters. Such parameters as solar radiation, salt fall, temperature, moisture, wind and site location influence the abundance and activity of microorganisms, therefore they play an important role in microbiological site severity.

In analyzing the test specimens, problems arose in judging the extent of fungal coverage on some samples and the minimal coverage on others. Fungal coverage was a subjective observation, but was independently judged by several observers–usually three.

- Relative Site Severity by Individual Materials

The pattern of fungus coverage on a descending scale of fungi coverage for each material follows the order: polyvinyl chloride, nylon, cotton, latex and butyl.

Polyvinyl Chloride (PVC): For fungus coverage of PVC (table 13) the forest sites and one mangrove site were statistically similar in severity. Within these five forest sites, including mangrove, Fort Clayton forest (ranked 16), mangrove (ranked 15), Coco Solo forest (ranked 13) and Gamboa forest (ranked 12) were experimental sites. Fort Clayton forest site is located on the Pacific side of the Isthmus; Gamboa forest site is located on the Atlantic slope of the continental divide at mid-Isthmus, but it was in geographical proximity to USATTC Headquarters on the Pacific side.

The sheltered sites, Chiva Chiva, Fort Gulick and Coco Solo, formed an essentially equivalent cluster which was intermediate in severity between the forested sites and the open and coastal sites. The open and coastal sites also formed an equivalent cluster which was least severe for microbial coverage of polyvinyl chloride.

Nylon: The forest (including mangrove) and shelter sites were statistically similar in severity for fungus coverage on nylon (table 14). Within these eight sites, five of them were experimental: Fort Clayton forest, Coco Solo shelter, Coco Solo forest, mangrove, and Gamboa forest. The Fort Clayton forest and Chiva Chiva shelter sites were the only sites located on the Pacific side of the Isthmus, but the Gamboa forest site, at mid-Isthmus, was most severe.

TABLE 13. SITE RANKS FOR POLYVINYL CHLORIDE BASED ON PERCENT AREA COVERAGE BY FUNGI AND SITE CLUSTERS DETERMINED BY DUNCAN'S MULTIPLE RANGE TEST ON DIFFERENCES BETWEEN PAIRS OF GRADE MEANS

Rank	Site‡	Mean Rating†	1 1.07	2 1.18	3 1.41	4 1.71	5 1.73	6 1.87	7 2.04	8 2.24	9 2.48	10 2.52	11 2.62	12 3.06	13 3.14	14 3.15	15 3.18	16 3.28	Duncan's Shortest Significant Ranges α = 0.01
1	Flamenco-C	1.07		0.11	0.34	0.64*	0.66*	0.80*	0.97*	1.17*	1.41*	1.44*	1.55*	1.99*	2.07*	2.08*	2.11*	2.21*	
2	Galeta-C	1.18			0.23	0.53*	0.55*	0.69*	0.86*	1.06*	1.30*	1.34*	1.44*	1.88*	1.96*	1.97*	2.00*	2.10*	R_2 = 0.437
3	Ft Sherman-O	1.41				0.30	0.32	0.46*	0.63*	0.83*	1.07*	1.11*	1.21*	1.65*	1.73*	1.74*	1.77*	1.87*	R_3 = 0.456
4	Chiva Chiva-O	1.71					0.02	0.16	0.33	0.53*	0.77*	0.81*	0.91*	1.35*	1.43*	1.44*	1.47*	1.57*	R_4 = 0.468
5	Ft Gulick-O	1.73						0.14	0.31	0.51*	0.75*	0.79*	0.89*	1.33*	1.41*	1.42*	1.45*	1.55*	R_5 = 0.477
6	Gun Hill-O	1.87							0.17	0.37	0.61*	0.65*	0.75*	1.19*	1.27*	1.28*	1.31*	1.41*	R_6 = 0.485
7	Gamboa-O	2.04								0.20	0.44	0.48*	0.58*	1.02*	1.10*	1.11*	1.14*	1.24*	R_7 = 0.491
8	Coco Solo-O	2.24									0.24	0.28	0.38*	0.82*	0.90*	0.91*	0.94*	1.04*	R_8 = 0.496
9	Chiva Chiva-S	2.48										0.04	0.14*	0.58*	0.66*	0.67*	0.70*	0.80*	R_9 = 0.501
10	Ft Gulick-S	2.52											0.10	0.54*	0.62*	0.63*	0.66*	0.76*	R_{10} = 0.505
11	Coco Solo-S	2.62												0.44	0.52*	0.53*	0.56*	0.66*	R_{11} = 0.508
12	Gamboa-F	3.06													0.08	0.09	0.12	0.22	R_{12} = 0.511
13	Coco Solo-F	3.14														0.01	0.04	0.14	R_{13} = 0.514
14	Ft Sherman-F	3.15															0.03	0.13	R_{14} = 0.517
15	Mangrove	3.18																0.10	R_{15} = 0.519
16	Ft Clayton-F	3.28																	R_{16} = 0.521

Indicates clusters of means not significantly different from each other

* Range is significant at the 0.01 level

†Means calculated from 4-week data points for four overlapping 48-week exposure phases

Harmonic Mean Sample Size (N_h) = 72.07

Standard Error of the Mean ($S_{\bar{x}}$) = 0.12

‡C = coastal; O = open; S = shelter; F = forest

TABLE 14. SITE RANKS FOR NYLON BASED ON PERCENT AREA COVERAGE BY FUNGI AND SITE CLUSTERS DETERMINED BY DUNCAN'S MULTIPLE RANGE TEST ON DIFFERENCES BETWEEN PAIRS OF GRADE MEANS

Rank	Site‡	Mean Rating†	1 1.50	2 1.50	3 1.86	4 1.99	5 2.06	6 2.25	7 2.30	8 2.36	9 2.55	10 2.59	11 2.60	12 2.70	13.5 2.71	15 2.82	16 2.89	Duncan's Shortest Significant Ranges $\alpha = 0.01$
1	Galeta-C	1.50		0.29	0.36	0.49*	0.56*	0.75*	0.80*	0.86*	1.05*	1.09*	1.10*	1.20*	1.21*	1.32*	1.39*	
2	Ft Sherman-O	1.79			0.07	0.20	0.27	0.46*	0.51*	0.57*	0.76*	0.80*	0.81*	0.91*	0.92*	1.03*	1.10*	$R_2 = 0.400$
3	Flamenco-C	1.86				0.13	0.20	0.39	0.44*	0.50*	0.69*	0.73*	0.74*	0.84*	0.85*	0.96*	1.03*	$R_3 = 0.420$
4	Chiva Chiva-O	1.99					0.07	0.26	0.31	0.37	0.56*	0.61*	0.61*	0.71*	0.72*	0.83*	0.90*	$R_4 = 0.430$
5	Gun Hill-O	2.06						0.19	0.24	0.30	0.49*	0.53*	0.54*	0.64*	0.65*	0.76*	0.83*	$R_5 = 0.440$
6	Ft Gulick-O	2.25							0.05	0.11	0.30	0.34	0.35	0.45*	0.46*	0.57*	0.64*	$R_6 = 0.444$
7	Gamboa-O	2.30								0.06	0.25	0.29	0.30	0.40	0.41	0.52*	0.59*	$R_7 = 0.450$
8	Coco Solo-O	2.36									0.19	0.23	0.24	0.34	0.35	0.46	0.53*	$R_8 = 0.455$
9	Ft Gulick-S	2.55										0.01	0.04	0.15	0.16	0.27	0.34	$R_9 = 0.459$
10	Ft Clayton-F	2.59											0.01	0.11	0.12	0.23	0.30	$R_{10} = 0.463$
11	Coco Solo-S	2.60												0.10	0.11	0.22	0.29	$R_{11} = 0.466$
12	Ft Sherman-F	2.70													0.01	0.12	0.19	$R_{12} = 0.467$
13.5	Coco Solo-F	2.71																$R_{13.5} = 0.471$
13.5	Chiva Chiva-S																	
15	Mangrove	2.82														0.11	0.18	$R_{15} = 0.474$
16	Gamboa-F	2.89															0.04	$R_{16} = 0.476$

Indicates clusters of means not significantly different from each other.

* Range is significant at the 0.01 level

†Means calculated from 4-week data points for four overlapping 48-week exposure phases

Harmonic Mean Sample Size $(N_h) = 70.92$

Standard Error of Means $(S_{\bar{x}}) = 0.11$

‡C = coastal; O = open; S = shelter; F = forest

The open sites were all statistically equivalent in severity with the exception of Fort Sherman open which was less severe. The Gamboa and Coco Solo open sites were most severe of open sites—both experimental.

PVC/Nylon Comparison: Between PVC and nylon, PVC had the greater amount of fungus coverage at the forest sites, but the extert of fungus coverage of nylon was more uniform between the forest sites. PVC exhibited a lower degree of coverage at the less severe site types, i.e., coastal and open. A comparison of the means for PVC and nylon (tables 13 and 14) shows PVC with only slightly more fungus coverage at all sites, but a marked difference in percent coverage at the various sites.

Variations in site order of fungus coverage at a few sites (e.g., Fort Clayton forest) were noted when comparing PVC and nylon. A logical explanation was that the large number of samples analyzed and numerous exposure racks covered relatively large exposure areas with different microenvironments—sunlight, moisture, sample temperature—at the same sites. These microenvironments could have created differing environmental severities consistent with material locations on an exposure rack.

Cotton: The two most severe sites for fungus coverage of cotton were the Fort Sherman and Gamboa forests (table 15). These two sites were statistically similar in severity. Gamboa site is located at mid-Isthmus and the Fort Sherman site, on the Atlantic side. Gamboa open and Gun Hill open (Pacific) were the most severe open sites and their severities were statistically similar. These two sites were experimental, as were all sites ranked 9 through 15.

The exposed cotton was woven while the other materials studied were continuous sheets. In the woven samples, the difference in surface texture and the intermingling of fabric strands made visible estimation of fungus coverage very difficult. It has been shown through microscopic studies (references 11, 46) that fungus hyphae enter the lumen of the cotton cell. Since the staple of cotton in cloth may be as long as three inches, the fungus growth in the cotton cell lumen may in fact greatly exceed that which is visibly apparent. The extent of fungus coverage at the most severe sites, the forests (table 15), was approximately equal to that observed on nylon; however, as with PVC, the coastal, open and shed sites produced much less coverage than the forest sites.

Latex: Fungus coverage on latex was least severe at the coastal and open sites as may be seen from table 16. Sites under forest canopies and shed roofs were the most heavily fungus-infested of the latex exposure sites. For latex, the most severe cluster of sites included both forest and shelter. This cluster also contained both experimental and established sites on both the atlantic and Pacific sides and at Gamboa.

Butyl: Numerous researchers (references 8, 10, 38, 41) have conducted field and laboratory deterioration tests on butyl and have found its utilization by microorganisms to be primarily limited to non-rubber constituents. The coastal and open sites were similar in fungus coverage with no significant differences among most sites. Data are presented in table 17 for fungus coverage of butyl.

TABLE 15. SITE RANKS FOR COTTON BASED ON PERCENT AREA COVERAGE BY FUNGI AND SITE CLUSTERS DETERMINED BY DUNCAN'S MULTIPLE RANGE TEST ON DIFFERENCES BETWEEN PAIRS OF GRADE MEANS

Rank	Site‡	Mean Rating†	1 0.67	2 0.83	3 0.91	4 0.96	5 1.09	6 1.17	7 1.46	8 1.63	9 2.03	10 2.09	11 2.15	12 2.30	13 2.42	14 2.57	15 2.74	16 3.10	Duncan's Shortest Significant Ranges α = 0.01
1	Chiva Chiva–S	0.67		0.24	0.24	0.29	0.42	0.50*	0.79*	0.96*	1.36*	1.42*	1.48*	1.63*	1.75*	1.90*	2.07*	2.43*	
2	Fort Gulick–C	0.83			0.08	0.13	0.26	0.34	0.63*	0.80*	1.20*	1.26*	1.32*	1.47*	1.59*	1.74*	1.91*	2.27*	R_2 = 0.437
3	Flamenco–C	0.91				0.01	0.18	0.26	0.55*	0.72*	1.12*	1.18*	1.24*	1.39*	1.51*	[illegible]	1.83*	2.19*	R_3 = 0.456
4	Fort Gulick–S	0.96					0.13	0.21	0.50*	0.67*	1.07	1.13*	1.19*	1.34*	1.46*	1.68*	1.78*	2.14*	R_4 = 0.468
5	Fort Sherman–O	1.09						0.08	0.37	0.54*	0.94*	1.00*	1.06*	1.21*	1.33*	1.48*	1.65*	2.01*	R_5 = 0.477
6	Galeta–C	1.17							0.29	0.46	0.86*	0.92*	0.98*	1.13*	1.25*	1.40*	1.57*	1.93*	R_6 = 0.485
7	Coco Solo–O	1.46								0.17	0.57*	0.63*	0.69*	0.84*	0.96*	1.11*	1.28*	1.64*	R_7 = 0.491
8	Chiva Chiva–O	1.63									0.40	0.46*	0.52*	0.64*	0.79*	0.94*	1.11*	1.47*	R_8 = 0.496
9	Coco Solo–S	2.03										0.06	0.12	0.27	0.39	0.54*	0.71*	1.07*	R_9 = 0.501
10	Gun Hill–O	2.09											0.08	0.21	0.35	0.48*	0.65*	1.01*	R_{10} = 0.505
11	Coco Solo–F	2.15												0.15	0.27	0.42	0.59	0.95*	R_{11} = 0.508
12	Gamboa–O	2.30													0.12	0.27	0.44	0.80*	R_{12} = 0.511
13	Mangrove	2.42														0.13	0.30	0.68*	R_{13} = 0.514
14	Fort Clayton–F	2.57															0.17	0.53*	R_{14} = 0.517
15	Gamboa–F	2.74																0.36	R_{15} = 0.519
16	Fort Sherman–F	3.10																	R_{16} = 0.521

Indicates clusters of means not significantly different from each other.

* Range is significant at the 0.01 level

†Means calculated from biweekly data points for four overlapping 24-week exposure phases

Harmonic Mean Sample Size (N_h) = 59.88

Standard Error of Means ($S_{\bar{x}}$) = 0.12

‡C = coastal; O = open; S = shelter; F = forest

TABLE 16. SITE RANKS FOR LATEX BASED ON PERCENT AREA COVERAGE BY FUNGI AND SITE CLUSTERS DETERMINED BY DUNCAN'S MULTIPLE RANGE TEST ON DIFFERENCES BETWEEN PAIRS OF GRADE MEANS

Rank	Site‡	Mean Rating†	1 0.31	2 0.36	3 0.38	4 0.40	5.5 0.53	7 0.56	8 1.06	9 1.25	10 1.44	11 1.51	12 1.59	13 1.75	14 1.78	15 1.99	Duncan's Shortest Significant Ranges $\alpha = 0.01$
1	Flamenco-C & Galeta	0.31		0.05	0.07	0.09	0.22	0.25	0.75*	0.94*	1.13*	1.20*	1.28*	1.44*	1.47*	1.68*	
2	Gamboa-O	0.36			0.02	0.04	0.17	0.20	0.70*	0.89*	1.08*	1.15*	1.23*	1.37*	1.42*	1.63*	$R_2 = 0.474$
3	Ft Gulick-O	0.38				0.02	0.15	0.18	0.68*	0.87*	1.06	1.13*	1.21*	1.37*	1.47*	1.61*	$R_3 = 0.493$
4	Gun Hill-O	0.40					0.13	0.16	0.66*	0.85*	1.04	1.11*	1.19*	1.35*	1.38*	1.49*	$R_4 = 0.507$
5.5	Coco Solo-O	0.53						0.03	0.53*	0.72*	0.91*	0.98*	1.06*	1.22*	1.25*	1.46*	$R_{5.5} = 0.517$
5.5	Ft Sherman-O																
7	Chiva Chiva-O	0.56							0.50*	0.69*	0.88*	0.95*	1.03*	1.19*	1.22*	1.43*	$R_7 = 0.524$
8	Mangrove	1.06								0.19	0.38	0.45	0.53*	0.69*	0.72*	0.93*	$R_8 = 0.532$
9	Ft Gulick-S	1.25									0.19	0.26	0.34	0.50	0.53*	0.74*	$R_9 = 0.538$
10	Chiva Chiva-S	1.44										0.07	0.15	0.31	0.34	0.55*	$R_{10} = 0.542$
11	Ft Clayton-F	1.51											0.08	0.16	0.27	0.48	$R_{11} = 0.547$
12	Coco Solo-S	1.59												0.16	0.19	0.40	$R_{12} = 0.551$
13	Gamboa-F	1.75													0.03	0.24	$R_{13} = 0.554$
14	Coco Solo-F	1.78														0.21	$R_{14} = 0.557$
15	Ft Sherman-F	1.99															$R_{15} = 0.560$

Indicates clusters of means not significantly different from each other.

*Range is significant at the 0.01 level

†Means calculated from weekly data points based on four consecutive 12-week exposure phases

Harmonic Mean Sample Size $(N_h) = 43.5$

Standard Error of the Mean $(S_{\bar{x}}) = 0.13$

‡C = coastal; O = open; S = shelter; F = forest

TABLE 17. SITE RANKS FOR BUTYL BASED ON PERCENT AREA COVERAGE BY FUNGI AND SITE CLUSTERS DETERMINED BY DUNCAN'S MULTIPLE RANGE TEST ON DIFFERENCES BETWEEN PAIRS OF GRADE MEANS

Rank	Site‡	Mean Rating†	1 0.61	2 0.83	3 0.88	4 0.92	5 0.93	6 0.95	7 1.03	8 1.04	9 1.17	10 1.22	11 1.23	12 1.24	13 1.27	14 1.30	15 1.46	16 1.59	Duncan's Shortest Significant Ranges, $\alpha = 0.01$
1	Flamenco–C	0.61		0.22*	0.27*	0.31*	0.32*	0.34*	0.42*	0.43*	0.56*	0.61*	0.62*	0.63*	0.66*	0.69*	0.85*	0.98*	
2	Chiva Chiva–O	0.83			0.05	0.09	0.10	0.12	0.20*	0.21*	0.34*	0.39*	0.40*	0.41*	0.44*	0.47*	0.63*	0.76*	$R_2 = 0.146$
3	Galeta–C	0.88				0.04	0.05	0.07	0.15	0.16	0.29*	0.34*	0.35*	0.36*	0.39*	0.42*	0.58*	0.71*	$R_3 = 0.152$
4	Fort Sherman–O	0.92					0.01	0.03	0.11	0.12	0.25*	0.30*	0.31*	0.32*	0.35*	0.38*	0.54*	0.67*	$R_4 = 0.156$
5	Gamboa–O	0.93						0.02	0.10	0.11	0.24*	0.29*	0.30*	0.31*	0.34*	0.37*	0.53*	0.66*	$R_5 = 0.159$
6	Gun Hill–O	0.95							0.08	0.09	0.22*	0.27*	0.28*	0.29*	0.32*	0.35*	0.51*	0.64*	$R_6 = 0.162$
7	Coco Solo–O	1.03								0.01	0.14	0.19*	0.20*	0.21*	0.24*	0.27*	0.43*	0.56*	$R_7 = 0.164$
8	Fort Gulick–O	1.04									0.13	0.18	0.19	0.20*	0.23*	0.26*	0.42*	0.55*	$R_8 = 0.165$
9	Chiva Chiva–S	1.17										0.05	0.06	0.07	0.10	0.13	0.29*	0.42*	$R_9 = 0.167$
10	Mangrove	1.22											0.01	0.02	0.05	0.08	0.24*	0.37*	$R_{10} = 0.168$
11	Fort Gulick–S	1.23												0.01	0.04	0.07	0.23*	0.36*	$R_{11} = 0.169$
12	Coco Solo–F	1.24													0.03	0.06	0.22*	0.35*	$R_{12} = 0.170$
13	Fort Clayton–F	1.27														0.03	0.19*	0.32*	$R_{13} = 0.171$
14	Fort Sherman–F	1.30															0.16*	0.29*	$R_{14} = 0.172$
15	Coco Solo–S	1.46																0.13*	$R_{15} = 0.173$
16	Gamboa–F	1.59																	$R_{16} = 0.174$

Indicates clusters of means not significantly different from each other.

* Range is significant at the 0.01 level

†Means calculated from 4-week data points for four overlapping exposure phases
Harmonic Mean Sample (N_h) = 59.22
Standard Error of the Mean ($S_{\bar{x}}$) = 0.04

‡C = coastal; O = open; S = shelter; F = forest

The Gamboa forest and Coco Solo shelter sites, both experimental, were the most severe for fungus coverage of butyl. The forest sites, except Gamboa, are within an equivalent cluster. Fort Clayton and Gamboa are both located in geographical proximity to USATTC Headquarters and would provide several logistical advantages while environmental severity would be equivalent to the Atlantic sites. Within the shelter sites, Coco Solo was the most severe. As for open sites, the Atlantic sites at Fort Gulick and Coco Solo were the most severe; Coco Solo was an experimental site.

- Relative Site Severity Based on Microbial Coverage for All Materials Combined

The general pattern of fungus coverage for each material approximated that observed in the combined materials analysis. Table 18 presents site severity differences in fungi coverage for all materials combined.

The sites with lowest fungal coverage were Flamenco coastal, Galeta coastal and Fort Sherman open site. The Fort Sherman open site was expected to be similar to coastal sites because of its proximity to the Caribbean Sea. The similarity of open sites to coastal sites was further borne out by the high salt fall measurements which typified coastal sites (table C-2). The lower fungus coverage at the coastal and coastal-like sites could reasonably be explained by: (1) the higher mean wind speed (table C-2) of the coastal sites—the adverse effect of air flow rates, shown by environmental chamber studies (reference 47), tends to discourage fungal growth because of the continual disruption and movement of the fungal spores; (2) the higher ambient salt levels occurring at coastal sites result in a selection of fungi more tolerant of salt and adverse osmotic gradients. The observed decrease in frequency of incidence or diversity is reflected in table C-5. Of the five different types of sites considered, coastal sites had the lowest incidence of all fungi with a median of 782; (3) the higher incidence of sunlight—the solar energy factor was of primary importance at open sites and will be discussed later in greater detail. It was difficult to separate and measure the effects of salt fall and solar energy because they may be cumulative, and their combination contributes to the overall effects of tropic deterioration. The recognition of the effects of the above parameters in the tropics is not new to the literature. They have been reported by many authors, e.g., Hutton, et al. (reference 35), Staffeldt, et al. (reference 48), Calderon, et al. (reference 13).

The following inland and open sites represented the next statistically equivalent cluster by fungus coverage: Fort Gulick, Chiva Chiva, Coco Solo and Gun Hill. A relatively high similarity in fungal coverage of most inland open sites was expected and was substantiated by lack of significant differences in fungus coverage among them. As might also have been expected, there were significant fungal coverage differences between inland open sites and coastal sites (table 18). Inland sites had considerably greater coverage than coastal. The observed total frequency of incidence of 903 was next to lowest (lowest being coastal, 782). The degree of severity of percent fungus coverage corresponded to the same pattern as frequency of incidence, with coastal sites the least severe and open sites slightly less severe.

The primary environmental factor limiting fungus coverage at the open sites was the higher incidence of ultraviolet radiation. Ultraviolet radiation is particularly destructive to microorganisms, e.g., Stanier, et al. (reference 48).

TABLE 18. SITE RANKS FOR ALL MATERIALS COMBINED BASED ON PERCENT AREA COVERAGE BY FUNGI AND SITE CLUSTERS DETERMINED BY DUNCAN'S MULTIPLE RANGE TEST ON DIFFERENCES BETWEEN PAIRS OF GRADE MEANS

Rank	Site‡	Mean Rating†	1 1.05	2 1.09	3 1.26	4 1.41	5 1.48	6 1.54	7 1.67	8 1.74	9 1.77	10 1.91	11 2.04	12 2.18	13 2.22	14 2.27	15 2.40	16 2.42	Duncan's Shortest Significant Ranges $\alpha = 0.01$
1	Flamenco-C	1.05		0.04	0.21	0.36*	0.43*	0.49*	0.62*	0.69*	0.72*	0.86*	0.99*	1.13*	1.17*	1.22*	1.35*	1.37*	
2	Galeta-C	1.09			0.17	0.32*	0.39*	0.45*	0.58*	0.65*	0.68*	0.82*	0.95*	1.09*	1.13*	1.18*	1.31*	1.33*	R_2 = 0.255
3	Ft Sherman-O	1.26				0.15	0.22	0.28*	0.41*	0.48*	0.51*	0.65*	0.78*	0.92*	0.96*	1.01*	1.14*	1.16*	R_3 = 0.266
4	Ft Gulick-O	1.41					0.07	0.13	0.26	0.33*	0.36*	0.50*	0.63*	0.77*	0.81*	0.86*	0.99*	1.01*	R_4 = 0.273
5	Chiva Chiva-O	1.46						0.06	0.19	0.26	0.29*	0.43	0.56*	0.70*	0.74*	0.79*	0.92*	0.94*	R_5 = 0.278
6	Coco Solo-O	1.54							0.13	0.20	0.23	0.37*	0.50*	0.64*	0.68*	0.73*	0.86*	0.88*	R_6 = 0.283
7	Gun Hill-O	1.67								0.07	0.10	0.24	0.37*	0.51*	0.55*	0.60*	0.73*	0.75*	R_7 = 0.286
8	Ft Gulick-S	1.74									0.03	0.17	0.30*	0.44*	0.48*	0.53*	0.66*	0.68*	R_8 = 0.289
9	Gamboa-O	1.77										0.14	0.27*	0.41*	0.45*	0.50*	0.63*	0.65*	R_9 = 0.292
10	Chiva Chiva-S	1.91											0.13	0.27	0.31	0.36*	0.49*	0.51*	R_{10} = 0.294
11	Coco Solo-S	2.04												0.14	0.18	0.23	0.36*	0.38*	R_{11} = 0.296
12	Mangrove	2.18													0.04	0.09	0.22	0.24	R_{12} = 0.298
13	Coco Solo-F	2.22														0.05	0.18	0.20	R_{13} = 0.299
14	Ft Clayton-F	2.27															0.13	0.15	R_{14} = 0.301
15	Ft Sherman-F	2.40																0.02	R_{15} = 0.303
16	Gamboa-F	2.42																	R_{16} = 0.304

Indicates clusters of means not significantly different from each other.

* Range is significant at the 0.01 level

†Means calculated from combining all data points for all materials

Harmonic Mean Sample Size (N_h) = 329.9

Standard Error of Mean ($S_{\bar{x}}$) = 0.07

‡C = coastal; O = open; S = shelter; F = forest

The morphological grouping of fungi observed at all test sites was primarily associated with the class *Deuteromycetes* order *Moniliales* (table C-4). The higher frequency of fungal incidence was in the family *Dematiceae* of the same order. This observation is of interest because the majority of these fungi are pigmented (table C-4). Other researchers, Calderon, et al. (reference 13), and Hutton, et al. (reference 35), have also observed a preponderance of pigmented fungi in areas of high solar radiation because these forms appear to be less detrimentally affected by sunlight than nonpigmented forms. It should be noted that in addition to the above mentioned family, many genera in other families observed were also pigmented (table C-4). An additional limiting factor at these sites was desiccation. The material samples at the open and coastal sites were subject to daily wetting/drying cycles. Active growth in most organisms is usually retarded by desiccation, e.g., Pelczar and Reid (reference 43).

The next equivalent group of sites are Gamboa open, Fort Gulick shed and Chiva Chiva shed. These sites were significantly lower in percent fungus coverage than coastal and inland open sites. On close examination of the environmental parameters at each site, the seemingly atypical order within this triad can be readily explained. The Gamboa open site had some of the characteristics of both an open and forest site which accounted for its atypical position in the severity of fungus coverage. In the vicinity of this open site, there was a considerable amount of tall grass *(Gynerium sagitatum)* which restricted the early morning and late afternoon sun; and during midday the sky was usually cloudy. Additional support was given the above observations because the overall global radiation measured at this site was lower by a substantial margin than that measured at the other open sites (table 1).

The sheltered sites appear to be intermediate between open and forest sites, because the shed provided protection from the majority of ultraviolet radiation and moisture was limited to wind-blown rain and condensation. This hypothesis was supported by the fact that the frequency of incidence (table C-5) of observed fungi at sheltered sites (997) was between that observed at open (903) and forest sites (1023). Also in the fungus coverage rating, the sheltered sites were intermediate in severity between most open and forest sites (table 18).

The next significantly different grouping was Coco Solo shelter, Mangrove, Coco Solo forest and Fort Clayton forest where an even greater percent fungus coverage was found. This grouping had a major overlap (table 18) with the final grouping, composed entirely of forest sites representing those with the greatest percent fungus coverage. The Coco Solo sheltered site did not fit with sheltered sites because it was too severe; nor did it fit with the forest sites because it was not as severe. This sheltered site was in between in fungus severity for no apparent environmental reason. As might have been expected, the forest sites (Mangrove, Coco Solo, Fort Clayton, Fort Sherman, and Gamboa) were the most severe when considering percent fungus coverage and frequency of incidence (1023) (table C-5). The environmental parameters found in the forest generally presented an ideal condition for fungus growth. The forests were characterized by (1) low light intensities, (2) high moisture during most of the day and night, (3) protection from severe desiccation, (4) stagnant air masses, (5) optimum temperature both day and night for maximum growth, and (6) low salt fall. The mangrove forest differed from other tropical forests because it lacks the great specie diversity normally found in upland tropical forests (table C-1). The presence of mangrove is due primarily to the unusual environment of tidal salt or brackish water inundations. The canopy is composed of trees of uniform height and open crowns as compared with most upland forests. The preceding factors and the high salt fall encountered in the Mangrove site made this site understandably less severe in fungus coverage than most other forest sites (table 18).

All of the forest sites were statistically equivalent in severity by fungus coverage for all materials combined. In this equivalent cluster, the Gamboa, Fort Clayton and Coco Solo forest sites were all experimental sites–Fort Clayton forest site is located on the Pacific side of the Isthmus and the Gamboa forest at mid-Isthmus.

Past tropic tests have been conducted predominantly at the Fort Sherman forest site on the Atlantic when testing for resistance to microbial attack. The finding that Gamboa and Fort Clayton forest sites are equivalent in severity could result in considerable logistical advantages during tropic tests if these Pacific side sites were to be used.

- Severity of Phases (Seasonal Effects)

The data were categorized into 16 primarily distinguishable patterns. These patterns were graphed according to specie and site. A few seasonal changes of fungi specie incidences were observed at different sites, but for the most part common fungal seasonal frequency patterns were almost nonexistent among the various exposure sites.

Summary Comparisons for Corrosion Weight Loss (CWL), Tensile Strength (TS), and Microbial Coverage (MC) as Indices of Site Severity

- Basis for Comparisons

When making comparisons across data that represent different units and scaling techniques (e.g., $\overline{\text{CWL}}$, $\overline{\text{TS}}$, and $\overline{\text{MC}}$) and that represent different materials, analyzing the rank orders of diverse measurements becomes meaningful. The multiple measurements on the various materials provide different means for ordering the test sites in terms of severity. Table 19 provides a side-by-side comparison of 12 separate rankings of site severity. The ranks are based on the data presented in previous tables. For each of the 12 sets of ranks, "1" means "most severe" and "16" means "least severe" for corrosion weight loss, tensile strength loss and percent area microbial coverage.

These rankings do not take into account the DMRT analyses previously applied to the data because of the many overlapping clusters of nonsignificantly different sites. Equal ranks were given where the severity means were numerically identical.

- Associations among Microbial Coverage and Tensile Strength

Correlation of Site Severity Rankings: Table 19 shows five materials providing site severity rankings on the basis of both MC and TS. The degree to which MC and TS rank the sites in the same severity order can be shown by calculating a Spearman (reference 52) rank correlation coefficient, r_s (r_s may vary from - 1.0, exactly opposite rank orders of site severity, to +1.0, representing exactly the same rank order). Table 20 lists the tensile strength and microbial coverage rank correlation coefficients for site severity.

TABLE 19. RANK ORDER* OF SITE SEVERITY FOR SIX MATERIALS BY CORROSION WEIGHT LOSS (CWL), TENSILE STRENGTH (TS), AND MICROBIAL COVERAGE (MC)

	Steel		Cotton		Nylon		PVC		Latex		Butyl	
	CWL	TS	MC	TS	MC	TS	MC	TS	MC	TS	MC	TS
COASTAL												
Flamenco	3	5	13	3	13	1	15	1	14.5	6	15	15
Galeta	2	2	10	4	15	2	14	7	14.5	4	13	11.5
SHELTER												
Chiva Chiva	13	16	15	14	3.5	8	8	10.5	6	10	8	16
Ft Gulick	11	13.5	12	12	8	9	7	10.5	7	9	6	13
Coco Solo	12	15	7	11	6	11	6	16	4	12	2	14
FOREST												
Ft Clayton	15	12	3	7	7	13	1	8	5	11	4	3.5
Gamboa	14	11	2	2	1	12	5	15	3	13	1	5
Coco Solo	10	4	6	13	3.5	14	4	14	2	14	5	2
Ft Sherman	5	3	1	1	5	15	3	13	1	15	3	3.5
OPEN												
Chiva Chiva	9	9.5	8	8	12	6	12	2.5	9	1	14	9.5
Gamboa	8	7	5	9	10	7	10	5	13	5	11	7
Coco Solo	7	8	9	10	9	5	9	6	10.5	2	10	7
Ft Sherman	6	9.5	11	6	14	4	13	2.5	10.5	3	12	11.5
Ft Gulick	4	6	14	5	11	3	11	4	12	7	9	7
MANGROVE	1	1	4	15	2	10	2	9	8	8	7	1
CONTROL	16	13.5	16	16	16	16	16	12	16	16	16	9.5

*Rank of 1 = most severe site; i.e., highest degradation in TS, highest CWL, highest MC.

TABLE 20. CORRELATION BETWEEN SITE SEVERITY RANKINGS: TENSILE STRENGTH LOSS CRITERION VERSUS MICROBIAL COVERAGE CRITERION

Material	Rank Correlation Coefficient (r_s)
Cotton	0.32
Nylon	-0.50
PVC	-0.56
Latex	-0.51
Butyl	0.39
Combined	-0.42

Differences in Tensile Strength and Microbial Coverage by Materials: Generally, the exposure sites with lowest fungus coverage exhibited the greatest loss of tensile strength for all materials combined ($r_s = -0.42$). Although none of the above correlation coefficients was significantly different from zero correlation ($\alpha = 0.01$), there were conflicting trends in the direction of the association of microbial coverage and tensile strength, between cotton and other materials such as nylon, PVC, and latex.

Cotton exhibited the greatest loss of tensile strength in the forest sites in contrast to the other materials. Cotton also exhibited the greatest fungus coverage in the forested sites (table 15). The association of the lowest tensile strength with the highest percentage fungus coverage suggests fungi as being primarily responsible for the deterioration observed in cotton. The anomaly of minor tensile strength losses in the mangrove and Coco Solo forest site cannot readily be explained by other than the earlier discussion of fungus coverage. Generally, those exposure sites with low fungus coverage exhibited the greatest loss of tensile strength. This suggests the possibility of observing the effects of solar radiation at some open sites, Fort Gulick and Fort Sherman, and a combination of solar radiation and fungi at the other open sites. The large loss in tensile strength of cotton at the coastal sites with a low percent fungus coverage indicated that ultraviolet radiation was the primary degrading parameter. Barghoon (reference 6) in his work with cotton found ultraviolet radiation in the tropics of primary importance in cotton deterioration with microbiological deterioration less significant.

For latex, the marked loss of tensile strength with the concurrent low fungal coverage indicated that fungal deterioration was relatively minor during this investigation. The low tensile strength found in conjunction with open and coastal exposure sites indicated ultraviolet radiation was responsible for the noted deterioration. This increase in ultraviolet with its concomitant sterilizing effect would also account for the lower fungus coverage in open and coastal sites.

In general, for polyvinyl chloride and nylon, the sites with the lowest fungus coverage had the lowest tensile strength and with the greatest fungus coverage the highest tensile strength (tables 7, 8, 13 and 14). This indicated that fungus coverage had little to do with PVC and nylon deterioration. Other environmental parameters, primarily solar radiation, are probably responsible for the loss of tensile strength. The degrading influence of sunlight has been reported by numerous researchers and field tests on PVC and nylon (references 9, 19, 24, 28, 32). Previous research work has substantiated that fungal growth on PVC results from the use of additives (reference 46). The limited use of these additives by microorganisms could result in severe fungus coverage without the concurrent loss of tensile strength.

Work by Teitell and Ross (reference 25) found that nylon 6 buried in the soil showed definite strength losses. These losses were much greater than could be caused by chemical effects and were attributed to microbial deterioration.

There were no significant differences in tensile strength loss of butyl among sites. However, small tensile differences observed for each site, when arranged in order of decreasing severity of tensile strength loss, conformed to the site type pattern observed with increasing fungus coverage for butyl. This finding suggests there may have been very minor fungal effect but the field exposure time was not long enough to produce significant differences. The lack of measurable deterioration in butyl further suggests that the fungi observed growing on this material were probably using nutrients precipitated from the surrounding environment and the butyl was acting as a biologically inert support for microbial growth.

● Associations among Corrosion Weight Loss and Tensile Strength

Table 19 shows one material–steel, providing site severity ranking on the basis of both corrosion weight loss and tensile strength. The coefficient of correlation for the two rankings was quite high (r_s = 0.84). There was perfect agreement that the two most severe sites were, first, the mangrove swamp, and next, the Atlantic coastal site on Galeta Island. The lease severe sites for both corrosive weight loss and tensile strength were the Fort Clayton and Gamboa forest sites and the shelter sites. The moderately severe sites were the Coco Solo and Fort Sherman forest sites and the open sites.

● Associations among Tensile Strength Measurements

Intercorrelations among Tensile Strength Site Severity Rankings from Six Materials: Table 19 shows a site severity ranking based on tensile strength for each of the six materials used in this investigation. Table 21 shows the coefficients of rank correlation derived from various pairs of the six rankings.

TABLE 21. INTERCORRELATIONS AMONG TENSILE STRENGTH SITE SEVERITY RANKINGS FROM SIX MATERIALS

	Steel	Cotton	Nylon	PVC	Latex
Cotton	.34				
Nylon	.25	.26			
PVC	.31	.27	.80†		
Latex	.22	.18	.86†	.83†	
Butyl	.52*	.04	-.48	-.22	-.26

* Significant at α = .05
† Significant at α = .01

Materials Yielding Similar Site Rankings: Nylon, PVC and latex were highly associated with each other on the basis of the order in which the sites degraded their tensile strength (average r_s = .83). For purposes of relative severity, the sites acted upon these three materials in the same manner, although the absolute severity of the tropic sites on the three materials differed (table 3). The most severe site for nylon and polyvinyl chloride was the same–the Pacific coastal site at Flamenco. Latex degradation differed somewhat with its most severe site being the Pacific open site in Chiva Chiva.

The order of site severity for butyl was somewhat the reverse of the order for nylon, latex and PVC, and was somewhat related to the same order as steel. However, the wide range of correlation coefficients for butyl should be interpreted in light of the lack of sensitivity of butyl tensile strength measurements for differentiating between sites (table 3).

Steel and cotton were unrelated to each other and to the other materials with respect to site severity order based on tensile strength.

On the basis of tensile strength site severity rankings alone, the six materials fell into four groups, each group having a different order in which the sites degraded their tensile strength: (1) steel, (2) cotton, (3) nylon/PVC/latex, (4) butyl.

● Associations among Microbial Coverage Measurements

Intercorrelations among Microbial Coverage Site Severity Rankings from Five Materials: Table 19 shows site severity rankings based on microbial coverage for each of five materials used in this investigation. Table 22 gives the coefficients of rank correlation derived from the various pairs of the five rankings.

TABLE 22. INTERCORRELATIONS AMONG MICROBIAL COVERAGE SEVERITY RANKINGS FROM FIVE MATERIALS

	Cotton	Nylon	PVC	Latex
Nylon	.59*			
PVC	.74†	.88†		
Latex	.64†	.84†	.85†	
Butyl	.65†	.85†	.88†	.90†

* Significant at $\alpha = .05$
† Significant at $\alpha = .01$

Materials Yielding Similar Site Rankings: Nylon, PVC, latex and butyl were associated with each other to a high degree with regard to order in which the sites produced microbial coverage (average $r_s = .87$). Microbial site severity order for cotton was also highly related to the rank order for the other four materials, but to a slightly less extent (average $r_s = .66$).

An examination of the microbial coverage site severity rankings in table 19 reconfirmed the high degree of similarity of site ranks. Generally, the forest sites produced the most severe coverage for all materials, followed by the mangrove, shelter, open and coastal sites, respectively.

● General Site/Mode Severity Order from All Materials Combined

To obtain an indication of the relative severity of the exposure sites in a sense that is generalized or averaged across all materials, the rankings in table 19 were summed across materials. Table 23 presents, for each site, a severity rank sum for tensile strength and microbial coverage. The overall rankings for sites and modes in table 23 were derived on the basis of the sum of ranks.

Before a discussion of which sites were generally most severe for tensile strength and microbial coverage, an observation should be made. In table 23, for both tensile strength and microbial coverage, all sites within a mode are clustered in an uninterrupted sequence of severity rank order. Although tables 10 and 11 show differences among some sites within a mode for specific materials, the analysis reveals the general trend for sites within a mode to be grouped next to each other in severity. This demonstration of "general modal homogeneity" based upon both tensile strength and microbial coverage serves as an empirical validation of the *a priori* grouping of sites into coastal, open, forest, and shelter modes. The mangrove site was originally classified in the forest mode, but was later considered a separate mode because of its uniquely high severity for steel. The mangrove site/mode was ranked next to the forest mode in overall severity for both tensile strength and microbial coverage. Because tensile strength and microbial coverage (i.e., microbial coverage as measured in this investigation) have been shown to be unrelated to each other, the validation of general modal homogeneity may be considered as coming from two relatively independent sources.

TABLE 23. OVERALL SITE/MODE SEVERITY ORDER FROM TENSILE STRENGTH AND MICROBIAL COVERAGE SUMMARY DATA

	Tensile Strength Sum across Six Materials			Microbial Coverage Sum across Five Materials		
	Sum of Ranks	Overall Ranks*		Sum of Ranks	Overall Ranks*	
		Sites	Modes		Sites	Modes
COASTAL						
Galeta	30.5	1	1	66.5	14	5
Flamenco	31	2		70.5	15	
OPEN						
Ft Gulick	32	3	2	57	12	4
Chiva Chiva	36.5	4.5		55	11	
Ft Sherman	36.5	4.5		60.5	13	
Coco Solo	38	6		47.5	9	
Gamboa	40	7		49	10	
MANGROVE	44	8	3	25	5	2
FOREST						
Ft Sherman	50.5	9	4	13	2	1
Ft Clayton	54.5	10		20	3	
Gamboa	58	11		12	1	
Coco Solo	61	12		20.5	4	
SHELTER						
Ft Gulick	67	13	5	40	7	3
Chiva Chiva	74.5	14		40.5	8	
Coco Solo	79	15		25	6	
CONTROL	83	16	6	80	16	6

*Rank of 1 = most severe site; i.e., highest degradation in tensile strength of highest percent microbial coverage.

For purposes of overall severity for all materials in general, it is meaningful to speak in terms of established modes. For purposes of severity for specific materials, the site/mode severity order in table 23 must yield to the more specific material site severity orders discussed earlier in this report.

The overall rank order of modes based on tensile strength degradation, found most severe in the coastal sites, was followed by the open, mangrove, forest and shelter sites in decreasing severity order. On the basis of microbial coverage, the forest sites were most severe for all materials, followed by the mangrove, shelter, open and coastal sites, respectively. These summary data show the rank order of sites and modes to be in the opposite direction for tensile strength versus microbial coverage. However, the trend does not hold for all materials and care should be taken not to generalize when data are available for specific materials. To the extent that a new material cannot be matched with a specific material used in this investigation, these general data take on meaning for the selection of optimum storage sites for deterioration studies.

Severity Comparisons

- Basis for Comparisons

Some sites used in this investigation have been established many years in locations representing coastal, open, forest and shelter storage and surveillance modes. More recently a number of experimental sites have been set up in areas previously not used. The locations of established and experimental sites are shown in figure 1. Savings in time and manpower were prime considerations in locating experimental sites closer to USATTC headquarters and laboratories both on the Atlantic and Pacific sides of the Canal Zone. Gamboa areas are considered Pacific side sites because the approach roads are arranged for easier access from the Pacific rather than the Atlantic side. However, the Gamboa sites are actually located on the Atlantic slope of the Continental Divide.

Comparisons of Atlantic versus Pacific sites, and established versus experimental sites, were made on the basis of site severity to determine if new sites could be used for accelerating natural tropic tests to shorten testing time. Also several of the new experimental sites offered logistical advantages over the established sites. Comparisons were made on the basis of site severity to locate more severe sites to reduce testing time and testing costs. With equally severe sites, the question of convenience, time and cost become the determining factor in the site selection.

The site severity comparisons were made on the basis of the data in table 19. Tables 24 and 26 average site severity ranks within a mode for each material. For instance, in table 19 under "Steel, $\overline{TS}$" there were two Atlantic shelter sites (Fort Gulick ranked 13.5 and Coco Solo ranked 15) with an average rank of 14.25. In the same ranking column, the Pacific shelter site, Chiva Chiva, was ranked 16th in severity. The average site severity rank for the shelter mode for steel was 14.3 for the Atlantic and 16.0 for the Pacific. The result of that comparison was that the Atlantic shelter sites were more severe than the Pacific shelter site on the basis of average degradation of tensile strength of steel.

All comparisons of average site severity rank in tables 24 and 26 were determined in the same manner. Tables 25 and 27, were constructed by displaying comparisons of greatest site severity by exposure mode and material.

- Site Severity Comparisons: Atlantic versus Pacific

Table 24 shows 44 comparisons—24 on the basis of tensile strength, and 20 on the basis of microbial coverage. Table 25 shows that 24 tensile strength comparisons resulted in 11 Atlantic sites being more severe and 13 Pacific sites. An 11/13 split on 24 comparisons is well within the limits of chance. Significance at $a = .05$ would require a 6/18 or more extreme split; at $a = .01$, a 5/19 or more extreme split would be required (against a null hypothesis of an even split). The 20 microbial coverage comparisons resulted in nine Atlantic sites and eight Pacific sites being most severe. Three comparisons showed no difference. On 20 comparisons, a significant split with $a = .05$ would be 5/15; with $a = .01$; a significant split would be 3/17. The overall distribution of severe sites was evenly split between the Atlantic and Pacific sides of the Canal Zone.

TABLE 24. AVERAGE SITE SEVERITY RANKS FOR ATLANTIC VERSUS PACIFIC SITES BY EXPOSURE MODE AND MATERIAL

Mode & Material	Average Site Severity Rank* Tensile Strength Atlantic	Tensile Strength Pacific	Microbial Coverage Atlantic	Microbial Coverage Pacific
COASTAL				
Steel	2.0	5.0	†	†
Cotton	4.0	3.0	10.0	13.0
Nylon	2.0	1.0	15.0	13.0
PVC	7.0	1.0	14.0	15.0
Latex	4.0	6.0	14.5	14.5
Butyl	11.5	15.0	13.0	15.0
SHELTER				
Steel	14.3	16.0	†	†
Cotton	11.5	14.0	9.5	15.0
Nylon	10.0	8.0	7.0	3.5
PVC	13.3	10.5	6.5	8.0
Latex	10.5	10.0	5.5	6.0
Butyl	13.5	16.0	4.0	8.0
FOREST				
Steel	3.5	11.5	†	†
Cotton	7.0	4.5	3.5	2.5
Nylon	14.5	12.5	4.3	4.0
PVC	13.5	11.5	3.5	3.0
Latex	14.5	12.0	1.5	4.0
Butyl	2.8	4.3	4.0	2.5
OPEN				
Steel	7.8	8.3	†	†
Cotton	7.0	8.5	11.3	6.5
Nylon	4.0	6.5	11.3	11.0
PVC	4.2	3.8	11.0	11.0
Latex	4.0	3.0	11.0	11.0
Butyl	8.5	8.3	10.3	12.5

*Ranks near 1 equal the most severe sites.
†Microbial coverage data not obtained for steel.

The summary figures in table 25 for exposure modes and materials showed the same fairly even distribution of severity with a few apparent exceptions for specific materials. All of the four comparisons based on tensile strength of PVC and all four based on microbial coverage for nylon showed the Pacific side was more severe. Although four comparisons were too few to determine statistical significance in the manner of the previous paragraph, these one-sided trends should be noted. The four comparisons based on tensile strength of steel also achieved a 4/0 imbalance, with the Atlantic side being more severe. This trend for steel should also be considered; however, the trend is academic in light of the one Atlantic/Pacific severity comparison that could not be made because there were no data for a Pacific mangrove site. The experimental Atlantic mangrove exposure site was the most severe for steel based on tensile strength loss.

It is not known if a Pacific mangrove site would be equally severe on steel, but such an hypothesis is tenable in view of the even split on severity order of the Atlantic versus Pacific comparisons that have been made.

TABLE 25. HIGHEST SITE SEVERITY*: ATLANTIC VERSUS PACIFIC SITES BY EXPOSURE MODE AND MATERIAL

	Highest Tensile Strength Severity (X)									
	Coastal		Shelter		Forest		Open		Total	
Material	Atl	Pac	Atl	Pac	Atl	Pac	Atl	Pac	Atl	Pac
Steel	X		X		X		X		4	0
Cotton		X	X			X	X		2	2
Nylon		X		X		X	X		1	3
PVC		X		X		X		X	0	4
Latex	X			X		X		X	1	3
Butyl	X		X		X			X	3	1
Total										
Atlantic:	3		3		2		3		11	
Pacific:				3		4		3		13

	Highest Microbial Coverage Severity (X)										
	Coastal		Shelter		Forest		Open		Total		
Material	Atl	Pac	Atl	Pac	Atl	Pac	Atl	Pac	Atl	Pac	Even
Cotton	X		X			X		X	2	2	0
Nylon		X		X		X		X	0	4	0
PVC	X		X			X	even		2	1	1
Latex	even		X		X		even		2	0	2
Butyl	X		X			X	X		3	1	0
Total											
Atlantic:	3		4						9		
Pacific:		1		1		4		2		8	
Even:	1		0		0		2				3

*X equals highest severity. Totals equal number of Xs.

● Site Severity Comparisons: Established versus Experimental

Table 26 shows 44 comparisons—24 on the basis of tensile strength severity rank and 20 on the basis of microbial coverage severity rank. Table 27 summarizes the comparisons and shows which comparisons resulted in the established sites being more severe. It also shows which comparisons resulted in the experimental sites being more severe. The data in table 26 represent an even distribution of severity across established versus experimental sites not only in an overall sense (12, 11, and 1 even, respectively, for tensile strength severity; and 10, 9, and 1 even, respectively, for microbial coverage severity) but also for specific modes and materials. It should be noted again that the highly severe experimental mangrove site had no established site comparison, and therefore could not be included in the above comparisons.

TABLE 26. AVERAGE SITE SEVERITY RANKS FOR ESTABLISHED VERSUS EXPERIMENTAL SITES BY EXPOSURE MODE AND MATERIAL

Mode & Material	Average Site Severity Rank*			
	Tensile Strength		Microbial Coverage	
	Established	Experimental	Established	Experimental
COASTAL				
Steel	2.0	5.0	†	†
Cotton	4.0	3.0	10.0	13.0
Nylon	2.0	1.0	15.0	13.0
PVC	7.0	1.0	14.0	15.0
Latex	4.0	6.0	14.0	14.0
Butyl	11.5	15.0	13.0	15.0
SHELTER				
Steel	14.8	15.0	†	†
Cotton	13.0	11.0	13.5	7.0
Nylon	8.5	11.0	5.8	6.0
PVC	10.5	16.0	7.5	6.0
Latex	9.5	12.0	6.5	4.0
Butyl	14.5	14.0	7.0	2.0
FOREST				
Steel	3.0	9.0	†	†
Cotton	1.0	7.3	1.0	3.7
Nylon	15.0	13.0	5.0	3.8
PVC	13.0	12.3	3.0	3.3
Latex	15.0	12.7	1.0	3.3
Butyl	3.5	3.5	3.0	3.3
OPEN				
Steel	8.3	7.5	†	†
Cotton	6.3	9.5	11.0	7.0
Nylon	4.3	6.0	12.3	9.5
PVC	3.0	5.5	12.0	9.5
Latex	3.7	3.5	10.5	11.8
Butyl	9.3	7.0	11.7	10.5

*Ranks near 1 equal the most severe sites.
†Microbial coverage data not obtained for steel.

TABLE 27. HIGHEST SITE SEVERITY*: ESTABLISHED VERSUS EXPERIMENTAL SITES BY EXPOSURE MODE AND MATERIAL

Highest Tensile Strength Severity (X)

	Coastal		Shelter		Forest		Open		Total		
Material	Est	Exp	Est	Exp	Est	Exp	Est	Exp	Est	Exp	Even
Steel	X		X		X			X	3	1	0
Cotton		X		X	X		X		2	2	0
Nylon		X	X			X	X		2	2	0
PVC		X	X			X	X		2	2	0
Latex	X		X			X		X	2	2	0
Butyl	X			X	even			X	1	2	1
Total											
Established:	3		4		2		3		12		
Experimental:		3		2		3		3		11	
Even:	0		0		1		0				1

Highest Microbial Coverage Severity (X)

	Coastal		Shelter		Forest		Open		Total		
Material	Est	Exp	Est	Exp	Est	Exp	Est	Exp	Est	Exp	Even
Cotton	X		X		X			X	3	1	0
Nylon		X	X			X		X	1	3	0
PVC	X			X	X			X	2	2	0
Latex	even			X	X		X		2	1	1
Butyl	X			X	X			X	2	2	0
Total											
Established:	3		2		4		1		10		
Experimental:		1		3		1		4		9	
Even:	1		0		0		0				1

*X equals highest severity. Totals equal number of Xs.

CONCLUSIONS

- A single tropic exposure site cannot be characterized as generally severe in deteriorative properties. The degree of severity is dependent on the material being exposed. For example, a site that is severely degrading for cotton may be benign for steel.

- The Atlantic and Pacific sides of the Isthmus provided exposure modes and sites equally severe on a representative cross section of types of materials, except for steel. (Steel attained its highest degradation at an Atlantic mangrove site, and could not be compared because no Pacific mangrove site was included in the investigation.) Therefore, future site selection for exposure tests need not necessarily be based on an assumed relationship between the known higher climatic severity of the Atlantic side and deterioration severity. This investigation demonstrated there is no one-to-one relationship between the two types of severity (table 25).

• The established and experimental sites were equally severe on a cross section of representative materials (table 27). Future site selection for exposure tests need not be based on the assumption that the most or least severe sites are those that have been in traditional use.

• It is possible to "accelerate" to some degree the results of natural tropic exposure tests by selection of sites. This conclusion is based on the fact that reliable statistical differences in deterioration rates exist among environmental exposure modes in close geographic proximity. Exposure modes, such as sheds, coastal sites, open sites and forest sites are not necessarily homogeneous with respect to severity of degradation. Significant differences were found within similar environmental exposure/modes with only a few exceptions.

• One of the major findings of this study was that the most severe test site for steel was the mangrove swamp. Deterioration at the mangrove site was accelerated by at least a factor of two over the next most severe site at Galeta coastal (figure 8).

• The following clusters of sites are considered generally homogeneous in deterioration (CWL) for steel:

Clusters

A Mangrove . . . . (most severe; causes greatest CWL)

B C-Galeta

C C-Flamenco
O-Gulick

D F-Fort Sherman
O-Fort Sherman
O-Coco Solo
O-Gun Hill
O-Gamboa
O-Chiva Chiva

E F-Coco Solo
S-Fort Gulick
S-Coco Solo
S-Chiva Chiva
F-Gamboa
F-Fort Clayton . . . . (least severe; causes least CWL)

• The following clusters of sites are considered generally homogeneous in deterioration rates (TS) for cotton:

Clusters

A F-Fort Sherman . . . . (most severe)

B F-Gamboa
C-Flamenco

Clusters (cont)

C C-Galeta
O-Fort Gulick
O-Fort Sherman
F-Fort Clayton
O-Chiva Chiva
O-Gamboa
O-Coco Solo
S-Coco Solo

D S-Fort Gulick
F-Coco Solo
S-Chiva Chiva
Mangrove . . . . (least severe)

• The following clusters of sites are considered generally homogeneous in deterioration rates (TS) for nylon:

Clusters

A C-Flamenco . . . . (most severe)
C-Galeta
O-Fort Gulick
O-Fort Sherman
O-Coco Solo
O-Chiva Chiva
O-Gamboa

B S-Chiva Chiva
S-Fort Gulick

C Mangrove

D S-Coco Solo
F-Gamboa

E F-Fort Clayton
F-Coco Solo
F-Fort Sherman . . . . (least severe)

• The following clusters of sites are considered generally homogeneous in deterioration rates (TS) for polyvinyl chloride:

Clusters

A C-Flamenco . . . . (most severe)

B O-Fort Sherman
O-Chiva Chiva
O-Fort Gulick

Clusters (cont)

C O-Gamboa
O-Coco Solo
C-Galeta

D F-Fort Clayton
Mangrove
S-Fort Gulick
S-Chiva Chiva
F-Fort Sherman
F-Coco Solo
F-Gamboa
S-Coco Solo . . . . (least severe)

- The following clusters of sites are considered generally homogeneous in deterioration rates (TS) for latex:

Clusters

A O-Chiva Chiva . . . . (most severe)
O-Coco Solo
O-Fort Sherman
O-Gun Hill
C-Galeta
O-Gamboa
C-Flamenco
O-Fort Gulick

B Mangrove
S-Fort Gulick

C S-Chiva Chiva

D F-Fort Clayton
S-Coco Solo

E F-Gamboa

F F-Coco Solo

G F-Fort Sherman . . . . (least severe)

- Relative differences in site severity were not isolated for butyl during this investigation. Exposure periods were not of sufficient length for environmental effects to produce deterioration based on tensile strength measurements.

- The relationship between tensile strength and microbial coverage depended upon the individual material. The two experimental measures were negatively (i.e., the more fungi, the less deterioration) related for all materials except cotton and butyl, for which they were slightly positively related (table 20).

• Corrosion weight loss and tensile strength are highly related indices of site severity on steel. Corrosion weight loss and tensile strength could be substituted for each other as measures of site severity on steel in certain cases. During tropic tests, selection of technique of measurement, corrosion weight loss or tensile strength, must be based upon the test item and test criteria (table 19).

• The site severity measure, tensile strength, did not produce the same site severity order for all materials. The six materials fell into four groups, each group having a different order in which the sites degraded their tensile strength: (1) steel, (2) cotton, (3) nylon/polyvinyl chloride/latex, and (4) butyl (table 21).

• The site severity measure, microbial coverage, produced essentially the same rank order of site severity for all materials measured. The microbial site severity orders for nylon, polyvinyl chloride, latex, and butyl were nearly identical, with the order for cotton being different but not to a significant extent (table 22).

• The sites within each given exposure mode demonstrated a general homogeneity on the basis of site severity rank order when the deteriorative properties of all materials were averaged for separate modes. That is, sites within a mode were always ranked next to each other based on combined materials rank analyses. The homogeneity was obtained from each of two independent site severity rankings—one based on tensile strength average for all materials combined and one based on microbial coverage average for all materials combined.

For purposes of overall severity for all materials combined, it is meaningful to speak in terms of exposure modes ranked in the following orders of highest severity:

Based on tensile strength: Coastal, open, mangrove, forest, shelter.

Based on microbial coverage: Forest, mangrove, shelter, open, coastal.

The above trends of modal severity do not necessarily hold for specific materials, and care should be taken not to generalize because data are available herein for specific materials. To the extent that a new material cannot be matched to a material having known site severity properties, the general exposure mode severity orders take on meaning for the selection of optimum storage sites for deterioration studies.

• The Atlantic slope of the Canal Zone has been generally believed to be a more degrading area for materials than the Pacific slope because of higher rainfall, relative humidity and salt fall, but the present study has shown this assumption to be not true in all cases. For example, the Flamenco coastal (Pacific) was the most severe site based on tensile tests for both nylon and polyvinyl chloride. For nylon, the next most severe site was Galeta coastal (Atlantic), but for polyvinyl chloride, Galeta coastal was the seventh most severe site. For latex, Chiva Chiva open (Pacific) was the most severe site followed by the Coco Solo open site (Atlantic). Also, the Gamboa forest site (geographically, mid-Isthmus), not the test site at Fort Sherman forest (Atlantic), was the most severe site for fungus coverage for all materials combined.

• A "worst case" tropic exposure mode cannot be selected solely on the basis of climatic criteria. Within a tropic area, other aspects of the microenvironment are more significant to deterioration than heat and humidity.

• The study failed to reveal significant differences in deterioration as a function of time of initial exposure. No differences in deterioration rates were found for any materials regardless of whether they were exposed in early or late wet or dry seasons. This determination was made by testing the slopes of regression lines representing different sample placement dates. The possibility of phase effects using a more sensitive research design is not ruled out.

RECOMMENDATIONS

• The following sites and modes of exposure are recommended for the desired rate of environmental severity applicable to general categories of materials based on the conditions of the present study. The reader is warned not to overgeneralize the recommendations for materials that differ radically in chemical composition from those used in the present study.

Metals

Site	Severity: Major	Moderate	Minor
Mangrove (Atlantic)	X		
C-Galeta (Atlantic)		X	
C-Flamenco (Pacific)			X
O-Chiva Chiva (Pacific)			X
O-Gamboa (mid-Isthmus)			X
O-Coco Solo (Atlantic)			X
F-Fort Clayton (Pacific)			X
F-Coco Solo (Atlantic)			X
O-Fort Gulick (Atlantic)			X
O-Fort Sherman (Atlantic)			X

Textiles

Site	Severity: Major	Moderate	Minor
F-Fort Sherman (Atlantic)	X		
F-Gamboa (mid-Isthmus)		X	
C-Flamenco (Pacific)		X	
C-Galeta (Atlantic)		X	
F-Fort Gulick (Atlantic)		X	
O-Fort Sherman (Atlantic)		X	
F-Fort Clayton (Pacific)		X	
O-Chiva Chiva (Pacific)		X	

Textiles (cont)

Site	Severity Major	Moderate	Minor
O-Gamboa (mid-Isthmus)			X
O-Coco Solo (Atlantic)			X
S-Coco Solo (Atlantic)			X
S-Fort Gulick (Atlantic)			X
F-Coco Solo (Atlantic)			X
S-Chiva Chiva (Pacific)			X
Mangrove (Atlantic)			X

Plastics

Site	Severity Major	Moderate	Minor
C-Flamenco (Pacific)	X		
O-Fort Sherman (Atlantic)		X	
O-Chiva Chiva (Pacific)		X	
O-Gamboa (mid-Isthmus)		X	
O-Coco Solo (Atlantic)		X	
O-Galeta (Atlantic)		X	
O-Fort Gulick (Atlantic)		X	
S-Chiva Chiva (Pacific)			X
Mangrove (Atlantic)			X

Rubber

Site	Severity Major	Moderate	Minor
O-Chiva Chiva (Pacific)	X		
O-Coco Solo (Atlantic)	X		
O-Fort Sherman (Atlantic)	X		
O-Gun Hill (Pacific)	X		
C-Galeta (Atlantic)	X		
O-Gamboa (mid-Isthmus)	X		
C-Flamenco (Pacific)	X		
O-Fort Gulick (Atlantic)	X		
Mangrove (Atlantic)	X		
S-Fort Gulick (Atlantic)	X		
S-Chiva Chiva (Pacific)		X	
F-Fort Clayton (Pacific)		X	
S-Coco Solo (Atlantic)		X	
F-Gamboa (mid-Isthmus)		X	
F-Coco Solo (Atlantic)			X
F-Fort Sherman (Atlantic)			X

Sites possessing the same level of severity should be selected on the basis of test cost and convenience.

- An investigation should be undertaken to develop a microbial coverage/penetration measurement technique capable of sensitively quantifying the various types and severity of microbial attack and distinguishing between destructive and nondestructive growth.

- Efforts should be made to continue to locate different types of sites which may be more severe than either the established or experimental sites used in this investigation. The Atlantic and Pacific sides of the Isthmus may generally be given equal priority in searches for new sites, depending upon material being exposed. More consideration should be given to cost, time and logistics during future site selection.

- Tropic Environmental Considerations, TECOM Test Operations Procedure 1-1-008, should be revised and updated to include tropic test site selection criteria based upon site severities determined during this investigation.

SECTION 3. APPENDICES

APPENDIX A. CORRESPONDENCE

(COPY)

DEPARTMENT OF THE ARMY
HEADQUARTERS, U. S. ARMY TEST AND EVALUATION COMMAND
Aberdeen Proving Ground, Maryland 21005

AMSTE-SA 8 January 1969

SUBJECT: Storage of Test Items

Commanding Officer
U. S. Army Tropic Test Center
Drawer 942
Fort Clayton, Canal Zone

1. One of the effects sought in tests of many items of materiel is that of storage. The determination of the storage effects is sometimes accomplished by periodic removal, examination, and operation. An example of the type of materiel which will undergo this sequence is the Test Set, Chemical Agent Alarm, XM74.

2. One of the many advantages of testing materiel in the Canal Zone is the availability of a variety of tropic environments. Because of this variety and the possibility of different effects of the environments on materials, the question arises as to whether the location of the storage area provides the maximum adverse environment to all types of materials. Conversely, should there be more than one storage area to obtain a better representation of the tropic environments? This question can be illustrated by the several locations used for the test panels.

3. Concurrent with the desire to optimize the storage location(s) is the importance of having a knowledge of the materials used in the assembly of an item and particularly those materials which might be adversely affected by a given environment. Also, there are perhaps other than deterioration characteristics which would result from storage in a specific location and these should be considered together with the types of materials.

4. Your comments on this matter are requested.

FOR THE COMMANDER:

/s/Benjamin S. Goodwin
/t/BENJAMIN S. GOODWIN
Special Assistant

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(COPY)
DEPARTMENT OF THE ARMY
HEADQUARTERS, U. S. ARMY TEST AND EVALUATION COMMAND
Aberdeen Proving Ground, Maryland 21005

Mr. Wise/js/5221

AMSTE-TS-M 6 April 1970

SUBJECT: Test Methodology Directive, Project 1E665702D625-09

Commanding Officer
US Army Tropic Test Center
Post Office Drawer 942
ATTN: STETC-TS-OP
Fort Clayton, Canal Zone

1. Reference letter, STETC-MR-D, dated 20 Mar 70, subject: Determination of Optimum Tropical Storage and Exposure Sites–Phase I.

2. The inclosed TRMS Forms STE 1188 and 1189 constitute a test directive for the task entitled:

9-CO-009-000-004 Determination of Optimum Tropical Storage and Exposure Sites–Phase I $19,000

3. Final reports are due in accordance with provisions of TECR 70-12. Interim reports for each task will be submitted in accordance with separate instructions provided for feeder reports for Improvement in Test Instrumentation and Methodology, RCS: OSCRD-134. Such reports will be submitted for report dates (30 September and 31 March) prior to completion of each task, and for the first report date following the testing completed (Test Event 40) date.

4. The test plan within the referenced letter is satisfactory. However, paragraph 14 should include the goal, "Collection of information for development of prediction models."

FOR THE COMMANDER:

/s/Frances T. Smith
/t/FRANCES T. SMITH
Asst Admin Officer

2 Incl
as

(END COPY)

(COPY)
DEPARTMENT OF THE ARMY
HEADQUARTERS, U. S. ARMY TEST AND EVALUATION COMMAND
Aberdeen Proving Ground, Maryland 21005

Mr. Wise/mgr/234-3350-5221

AMSTE-TS-M

18 September 1970

SUBJECT: Determination of Optimum Tropical Storage and Exposure Sites–Phase I, TRMS No. 9 CO 009 000 006.

Commanding Officer
US Army Tropic Test Center
ATTN: STETC-MR
Drawer 942, Fort Clayton, Canal Zone

1. Reference USATECOM Regulation 70-12, dated 3 August 1970.

2. This letter and attached TRMS forms 1188 and 1189 (Incl 1) constitute a test directive for the subject investigation under the USATECOM Methodology Improvement Program, RDT&E 1E665702 D625. The authorized cost is $19,000.

3. Interim and final reports are due in accordance with the reference. Interim reports will be submitted for each reporting period through the first report date following completion of the investigation.

4. Special Instructions:

a. TRMS No. 9-CO-009-000-006 replaces FY 70 TRMS No. 9-CO-009-000-004, for the subject investigation. All technical and financial aspects of the investigation as approved in FY 70 remain unchanged. Any deviation from the approved scope, procedures or authorized cost will require approval from this headquarters prior to execution.

b. New MTP's or required revisions to existing MTP's which are required as a result of this investigation must be prepared and submitted to this headquarters with the final report.

FOR THE COMMANDER:

1 Incl
as

/s/George T. Morris, Jr.
/t/GEORGE T. MORRIS, JR.
Colonel, GS
Director, Test Systems Analysis

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(COPY)
DEPARTMENT OF THE ARMY
UNITED STATES ARMY TROPIC TEST CENTER
Fort Clayton, Canal Zone

STETC-PD-M 13 March 1972

SUBJECT: Determination of Optimum Tropical Storage and Exposure Sites—Phase I and Phase II

Commanding General
US Army Test and Evaluation Command
ATTN: AMSTE-PA-M
Aberdeen Proving Ground, Maryland 21005

1. References:

a. Letter, AMSTE-PA-M, 21 July 1971, subject: Determination of Optimum Tropical Storage and Exposure Sites—Phase I—TRMS No. 9-CO-009-000-006.

b. Letter, AMSTE-PA-M, 21 July 1971, subject: Determination of Optimum Tropical Storage and Exposure Sites—Phase II—TRMS No. 9-CO-009-000-005.

2. Referenced methodology investigations require a four month extension beyond the scheduled test completion date of June 1972 for the following reasons:

a. The investigations were proposed and approved as a two year effort. The investigations were formally initiated in September 1970.

b. Data analysis is presently behind schedule due to chemical instrumentation maintenance and repair difficulties experienced during the last 12 months. The infrared spectrophotometer, one of the basic tools, became totally inoperative and a new instrument is under procurement. As a result, a very large chemical backlog has built up. Procurement delays were also experienced in obtaining accessories for the tensile tester.

c. Our initial recruitment effort for the materials engineer and chemist vacancies was successful only after the investigation was 7 months underway. Now the chemist position is vacant due to resignation and new recruitment action is being followed. A replacement is not expected until approximately 1 May 1972.

3. Upon approval of extension to 31 October 1972, this Center will initiate the required TRMS changes.

FOR THE COMMANDER:

/s/Robert H. Murff
/t/ROBERT H. MURFF
CPT, AGC
Administrative Officer

AMSTE-ME (13 Mar 72) 1st Ind 21 Mar 1972

SUBJECT: Determination of Optimum Tropical Storage and Exposure Sites—Phase I and Phase II

Headquarters, US Army Test and Evaluation Command, Aberdeen Proving Ground, Maryland 21005 23 Mar 1972

TO: Commanding Officer, US Army Tropic Test Center, ATTN: STETC-PD-M, Drawer 942, Ft Clayton, CZ

1. Reference letter AMSTE-PA-M, 9 March 1972, subject: Preparation of FY 1973 Execution Plan—Methodology Improvement Program.

2. The recommended extension of methodology investigations, "Determination of Optimum Tropical Storage and Exposure Sites (Phase I and II)"—TRMS numbers 9-CO-009-000-005 and 9-CO-009-000-006 has been approved.

3. Extension of the investigations to 31 October 1972 will require the use of FY 73 funds starting on 1 July 1972; consequently, these investigations must be included in the response to Reference 1. In addition, any FY 72 funds associated with these investigations that cannot be obligated as a result of the delay in effort must be returned to this headquarters.

4. Request that information concerning unobligated FY 72 funds associated with the subject methodology efforts be provided to this Headquarters, ATTN: AMSTE-ME by COB 24 April 1972.

FOR THE COMMANDER:

/s/W. I . Stone, LTC
/t/GEORGE T. MORRIS, JR.
Director, Plans and Analysis

(END COPY)

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Updated 17 April 1972

1. TITLE: Determination of Optimum Tropical Storage and Exposure Sites 9 CO 009 000 006

2. INSTALLATION: US Army Tropic Test Center
P. O. Drawer 942
Fort Clayton, Canal Zone

3. PRINCIPAL INVESTIGATOR: George W. Gauger
Analysis Division
STETC-AD
Autovon 313-2 87-3762

4. STATEMENT OF THE PROBLEM: Tropic storage deterioration testing currently being conducted at the Tropic Test Center is of doubtful validity because test items are being exposed only in a few areas in close geographical proximity. Deterioration is currently being determined by visual observations only. No measurements of the extent or rate of deterioration are being conducted. Test items frequently are limited in number and only three or four may be available. These items cannot be subjected to destructive testing because they must be returned to the testing agency, hence it is impossible to determine the cause of failure.

5. DESCRIPTION OF INVESTIGATION: a. The U.S. Army Tropic Test Center will determine optimum sites for tropical materiel tests by determining the severity of deterioration of selected materiel exposed in present exposure sites and in new exposure sites. Deterioration rate data will be collected from the materials exposed at each site. The data will be collected from the materials exposed at each site. The data obtained will then be used to classify the deterioration severity of a given site. A variety of representative materials commonly used as components of materiel end-items will be exposed. TTC will also develop nondestructive techniques for measuring material deterioration.

b. The U. S. Army Tropic Test Center (TTC) will undertake the following investigations:

(1) Survey the existing literature that pertains to deterioration of materials exposed to the tropics. Technical repositories, such as the Defense Documentation Center, Armed Service Technical Information Agency, Remote Area Conflict Information Center and specialized libraries will be asked to supply pertinent information. Military sources such as Technical Manual 743-200, "Storage of Materiel" will also be surveyed for relevant information.

(2) Select basic materials used in the construction of military items. These materials must be composed of known ingredients, so that accurate and reliable deterioration rates can be established. These materials will include paints, polymers, metals, elastomers, paper, and cloth.

(3) Determine the relative severity of effects of the different environments available for the Center's use. Many different environments, including: open, savannah, evergreen forest, semideciduous forests, and coastal sites exist in the Canal Zone, however not all of them have been "calibrated" with respect to deterioration severity.

(4) Measure auxiliary atmospheric measurements such as: microclimates, salt content, solar radiation, ozone, and microbial content at selected sites.

(5) Determine onset of deterioration as opposed to failure by measuring as many deterioration changes as possible, by the use of destructive and nondestructive test methods. The technical literature will constantly be surveyed to incorporate new techniques into the program.

(6) Determine deterioration rates and patterns. Deterioration rates and patterns can be detected with the aid of the microscope and specialized photoelectric spectrophotometers. These instruments will be utilized in this investigation.

(7) The results, if definitive, will be incorporated into a new tropic storage and exposure TOP.

6. REASONS FOR CONDUCTING INVESTIGATION: a. Present Capability.

(1) Microbiological inspections and services were conducted on 63 tests during the past three years. The information gathered, however, has not allowed the development of cause and effect relationships because the number of test items were limited and could not be destroyed in testing. It is therefore oftentimes impossible to determine the rates, patterns, and reasons for failure of the test items.

(2) The effects of tropic environmental storage are presently determined by the detection of gross changes in materiel (rips, cracks, fading, softening, etc.).

(3) Over 80% of tropic storage testing is conducted at two sites representing only two environmental types.

(4) Many of the storage and exposure sites now available for TTC use were selected for practical reasons with little consideration for significant environmental conditions.

b. Limitations of Present Capability.

(1) A greater number of material samples must be exposed so that cause and effect relationships can be established.

(2) Methods of detecting non-visual deterioration changes on materiel end-items must be developed.

(3) Deterioration rates and patterns must be determined for all major vegetation terrain types available to TTC to assure adequate testing under representatively severe conditions.

(4) A greater number of test sites must be used. Several natural environmental types exist in the Canal Zone, however, the deterioration severity of the sites and their suitability for testing certain kinds of materials has not been ascertained.

c. Anticipated Improvements to Result from Investigation

(1) Establish cause and effect relationships between environment and materiel.

(2) Detect early manifestations of deterioration.

(3) Establish deterioration rates and patterns.

(4) Determine optimum uses of each TTC storage and exposure site by calibrating sites with respect to known severity.

d. Pertinence to TECOM Mission.

TECOM bears major responsibility for the tropic tests of Army materiel items, thus investigations that will define optimum test sites for equipment will benefit TECOM operations more than any other organization. The present investigation will use non-test data to benefit test methodology.

AMC sponsored deterioration projects (Frankford Arsenal, USAECOM, USAMERDC) in the Canal Zone do not address the same objectives as the present project. The AMC projects are long-term (5–25 years) and are done mostly in coastal sites. The AMC projects are designed to follow the materials through to complete destruction or failure. This Center has supported the AMC tests for eight years and has received no feed back to assist the test effort. The present project is designed to yield a higher data rate and to use more sophisticated laboratory analyses than the AMC projects.

7. <u>IMPACT IF NOT FUNDED OR DELAYED</u>. a. Impact statements for the following two conditions:

(1) The investigation will not be conducted.

(a) Effects of failure to fund:

(i) TTC storage and exposure sites cannot be calibrated for environmental severity.

(ii) Nondestructive test methods will not be developed.

(iii) The tropical storage and exposure TOP will not be written.

(iv) Methods for shortening tropic storage tests will not be developed.

(v) Failure expectancies representative of components used in end item of materiel will not be established.

(b) List of requirements taken from specified requirements documents (QMR, SDR) which will not be met due to inability either to adequately test or analyze the resulting test data.

(i) Small Development Requirement for Remote Area Lightweight Multi-Weapons Armorer's Repair Kit. "Be resistant to fungi, insects, mildew, corrosion, moisture and vapor."

TITLE: Determination of Optimum Tropical Storage and Exposure Sites 9 CO 009 000 006

(ii) "Be capable of safe storage (5 years) and transportation by individuals participating in missions within an Unconventional Warfare Operational Area under hot-dry, warm-wet, intermediate, and cold climate conditions, as defined in paragraph 7, C1, AR 705-15."

(iii) "Small Development Requirement for Army Aircraft Weapons Handling Vehicle, Multipurpose." "Materials will be such as to provide maximum resistance to rust, corrosion and deterioration in service and prolonged storage." "Construction materials used will provide maximum resistance to harmful effects on rodents, fungi, humidity, rain, snow, salt water, and wind and will have a useful life span of at least 10 years."

(iv) Small Development Requirement for a Lightweight Camouflage Screening System. "Be resistant to mold, rot, fungus, corrosion, and color fading."

(v) Small Development Requirement for Cold Water Detergent. "Detergent shall remain stable in storage under conditions defined in AR 705-15, para 7a, b, c, and d."

(vi) Small Development Requirement for Epidemiological Survey Kit. "The end times contained within the inserts must be resistant to moisture and fungus type deteriorations encountered in hot-wet environment. Exterior carrying case and internal inserts must withstand the moisture hazard encountered on fording small rivers and streams, to the same degree as the Portable Medical Laboratory referred to in paragraph 2b(2)(g)."

(vii) Small Development Requirement for Lightweight Recompression Chamber. "Use construction materials that will provide maximum resistance to harmful effects of rodents, insects, fungi, humidity, rain, snow, ice, salt water, and wind."

(viii) Small Development Requirement for a Multicircuit firing Device. "Have a 95% probability of functioning as described in 2c(11) above in wet-warm, wet-hot, humid-hot coastal desert, hot dry, intermediate hot-dry, intermediate cold and cold climate categories after field storage for at least 3 months prior to use and transportation in using unit vehicles or trailers for 3000 miles - - -"

(ix) Small Development Requirement for Lightweight, Expendable Pallet, Airmobile. "The expandable pallet shall be resistant to all usual weather conditions encountered in Army supply and storage operations in the field." "Preclude softening beyond use under tropic conditions." "Withstand rain (water) that may be expected under monsoon conditions common to S.E. Asia."

(x) Small Development Requirement for a Portable Sign Making Kit. "Be capable of being employed and functioning properly and/or stored under field conditions in hot dry, warm wet, intermediate and cold climatic conditions as defined in para 7, C1, AR 705-15."

(xi) Small Development Requirement for Remote Area Demolitionist's Equipment Kit. "Be capable of being employed and functioning properly and/or under field conditions in wet-warm, wet-dry, humid-hot coastal desert, hot-dry, intermediate hot dry, intermediate cold and cold climatic categories defined in Chapter 2, AR 70-38." "Except for active explosions and impairment of capabilities from effects of extreme conditions for 2 years in warm-wet, wet-dry, humid-hot coastal desert, hot-dry, intermediate hot dry, intermediate cold and cold climatic categories defined in Chapter 2, AR 70-38."

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(xii) Small Development Requirement for a Water Quality Analysis Set. "Set shall be capable of operation, safe storage and transportation without permanent impairment of its capabilities from the effect of climatic categories 1, 2, 3, 4, 5, and 6 as delineated in AR 70-38."

(2) The investigation will be deferred until the FY 74.

(a) Effects of delay in funding.

(i) Delay maximum effective use of the natural environments available.

(ii) Delay the optimum use of TTC's storage and exposure sites.

(iii) Delay development of methods for shortening and improving tests.

(iv) Delay the establishment of a tropical storage and exposure MTP.

(v) Delay the establishment of failure expectancies representative of components used in end item of materiel.

(vi) Delay development of nondestructive tropic tests of materiel.

(vii) Scientific and engineering man-hours and $30,414 spent to date would be wasted.

(b) Same as paragraph 7(1)b.

(3) Man-hours and dollars spent to date: Man-hours—4,544 Dollars—$30,414.

8. TEST PROJECTS TO BENEFIT FROM THE INVESTIGATION:

TITLE	TRMS NO.				FY		
				74	75	76	77
Missile, 152mm Heat MGM 51	1MI	014 051	002	SU	SU	SU	SU
Missile, Shillelagh, Spt Storage Test	1MI	014 051	008	ST	ST	ST	ST
Rocket Motor M66 Tropic Storage	2MI	111 066	001				
Propellants, Prediction, Safe Life	2MU	005 000	001	PI			
Surveillance Program for S&A Device M30A1 (Nike Hercules)	3MI	080 030	002	SU	SU	SU	SU
Mask, Aircraft, Protective M24	5EI	820 024	005	SU	SU	SU	SU
Mask, Protective, Tank, M25A1	5EI	820 025	001	SU	SU	SU	
Detector Unit, Chemical Agent, Alarm XM8	5ES	300 008	004	SU	SU	SU	SU
Kit, Sampling & Analysis, CBR, M-19E34	5ES	630 019	003	SU	SU	SU	SU
Kit, Chemical Agent, Detector, M18A2	5ES	680 018	004	SU	SU	SU	SU
Burster, Field, Incendiary M4	5MU	018 004	005	SU	SU	SU	
Launcher, Tactical, CS, 16 Tube	5WE	F00 008	001	SU	SU	SU	
TOW 15 yr Surveillance Program	8MI	000	TOW013	SU	SU	SU	SU

TITLE: Determination of Optimum Tropical Storage and Exposure Sites 9 CO 009 000 006

9. RESOURCES: a. Financial

	Dollars in Thousands FY 73		
	In-house		Out-of-house
Personnel Compensation			
Permanent Full-time	7.8		—
Part Time			
Travel	—		—
Contractual Support	—		—
Consultants & Other Svcs	—		—
Materials & Supplies	2.0		—
Equipment	—		—
G&A Costs	15.1		
Subtotals	24.9		0
FY Total		24.9	

b. Explanation of Cost Categories.

(1) N/A

(2) N/A

(3) Contractual support will be required to assist in data collection, storage and reduction.

(4) N/A

(5) N/A

(6) N/A

(7) G&A Costs are computed at the rate of $15.50 per direct labor man-hours. This rate, provided by TTC Budget Office, includes overhead cost and host-tenant agreement support cost.

c. Obligation Plan.

FY 73

FQ	1	2	3	4	TOTAL
	18.6	6.3			24.9

d. In-House Personnel.

	Number	Man-hours, FY 73 Required	Available	Total Man-hours Required
Microbiologist, GS 0403	1	200	200	400
Materials Engineer, GS 0806	1	200	200	400
Chem Engr Asst (01G20)	1	320	320	640
Chemist, GS 1320	1	200	0	200
Engineer Tech, GS 0802	1	20	20	40
Meteorologist, GS 01340	1	35	35	70
		975	775	1750

TITLE: Determination of Optimum Tropical Storage and Exposure Sites 9 CO 009 000 006

(2) Resolution of nonavailable personnel. Chemist position is a TDA slot presently vacant but candidate has been selected and is expected to be available on or about 1 May 1972.

10. INVESTIGATION SCHEDULE:

	FY 72
	J A S O N D
In-house	– – – – – – R
Contract	– – – –

Consultants: Not applicable.

11. ASSOCIATION WITH IMP: N/A

12. ASSOCIATION WITH MTP/TOP PROGRAM: A new Test Operations Procedure will be written titled, "Tropic Exposure Considerations."

/s/Hyrum Dallinga
/t/HYRUM DALLINGA
COL, Inf
Commanding

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(COPY)
DEPARTMENT OF THE ARMY
HEADQUARTERS, U. S. ARMY TEST AND EVALUATION COMMAND
Aberdeen Proving Ground, Maryland 21005

Mr. Champion/dg/870-5332

AMSTE-ME 21 July 1972

SUBJECT: Determination of Optimum Tropical Storage and Exposure Sites–Phase I, TRMS No. 9-CO-009-000-006

Commanding Officer
USA Tropic Test Center
ATTN: STETC-PD-M
Drawer 942
Ft. Clayton, CZ

1. Reference TECOM Regulation 70-12 dated 3 August 1970.

2. This letter constitutes a test directive for continuing the subject investigation under the TECOM Methodology Improvement Program, RDT&E 1U665702D625.

3. Subject investigation is recognized by this headquarters as a multi-year effort. The authorized cost for FY 73 is $24,900.

4. Special Instructions.

a. The methodology investigation proposal (Incl 1) is the basis for headquarters technical and financial approval of the subject investigation. Any deviation from the approved scope, procedures or authorized cost will require approval from this headquarters prior to execution.

b. An interim report will be submitted to this headquarters, ATTN: AMSTE-ME, on 15 November 1972 and the final report is due 15 January 1973.

c. Required changes in TRMS will be made by TTC.

d. Recommendations on new TOPs or revisions to existing TOPs will be included as part of the Recommendation Section of the final report. New or revised TOPs will not be required to be submitted with the final report. Final decision on the scope of the TOP effort will be made by this headquarters as part of the report approval process.

5. In case of conflict, guidance provided in this letter will take precedence over that shown in reference 1a.

FOR THE COMMANDER:

/s/Sidney Wise
/t/SIDNEY WISE
Methodology Improvement Dir

1 Incl
as

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APPENDIX B. REFERENCES

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APPENDIX C. DATA

TABLE C-1. BOTANICAL CHARACTERIZATIONS AT EXPOSURE SITES

Canopy Trees (20 to 35 meters tall)

Species	Atlantic Mangrove	Gamboa Forest	Fort Sherman Forest	Coco Solo Forest	Pacific Forest
Acrocomia sclerocarpa		X	*		
Anacardium excelsum		X		X	X
Apeiba tibourbou		X			
Avicennia nitida	X				
Cordia alliodora				X	
Cupania sylvatica		X			
Hieronyma laxiflora		X			
Laguncularia racemosa	X				
Luehea seemanii		X			
Ormosia coccineae				X	
Paulsenia amata		X			
Pourouma scobina		X			
Proteium glabrum				X	
Proteium tennifolium		X			
Pseudobambax septinatum		X			
Rhizophora mangle	X				
Total species per 0.4 hectare	3	10	*	4	1

* Not listed as none of the trees are tall enough to be considered true canopy.

Sub-Canopy Trees (10 to 20 meters tall)

Species	Atlantic Mangrove	Gamboa Forest	Fort Sherman Forest	Coco Solo Forest	Pacific Forest
Acrocomia schlerocarpa		X		X	
Anacardium excelsum					X
Apeiba tibourbou			X		X
Ardisia		X			
Bactris minor		X			
Cecropia		X			
Croton billbergianus			X		
Erythrina			X		
Eugenia		X			
Ficus			X		
Ficus tonduzii			X		
Foramea occidentalis				X	
Genipa americana				X	
Grias fendleri			X		
Guatteria			X		
Gustavia superba		X			
Heisteria longipes			X		
Hirtella americana				X	
Hirtella racemosa					X
Inga goldmanii			X		

Sub-Canopy Trees (C-1 cont) Species	Atlantic Mangrove	Gamboa Forest	Fort Sherman Forest	Coco Solo Forest	Pacific Forest
Macrocnemum glabrescens			X		
Miconia argentea					X
Nectandra			X		
Nectandra gentle					X
Olmedia aspera			X		
Palm (genus unknown)				X	
Paulsenia amata		X	X		
Piper reticulatum		X			X
Proteium glabrum				X	
Quassia amara				X	
Scheelea zonensis		X			
Solanum hayesii			X		
Sorocea affinis				X	
Terminalia amazonica			X		
Tillisia nervosa			X		
Trichospermum pa.amensis			X		
Triplaris cummingaiana					X
Zanthoxylum			X		
Total species per 0.4 hectare	0	9	18	8	7

Shrubs (1 to 8 meters high)

Aechmea magdalense		X		X	
Acalypha diversifolium		X			
Acrostichum	X				
Alibertia edulis					X
Ardisia		X			X
Arthrostylidium racemiflorum					X
Asterogyne			X		
Bactris			X		
Bactris minor					X
Brosimum oernadettae				X	
Brownea macrophylla				X	
Calathea		X			
Calathea insignus			X		
Capparis budacca				X	
Carludovica palmata					X
Cestrum			X		
Citharexylum caudatum	X				
Clavija			X		
Connarcus turczinaowii				X	
Copaifera panamensis					X
Costus		X			
Cupania papillosa			X		
Cupania sylvatica		X			
Desmoncus isthmicus					X
Desmopsis panamensis		X		X	
Dieffenbachia				X	
Dimerocostus Strobalanus			X		

Shrubs (C-1 cont) Species	Atlantic Mangrove	Gamboa Forest	Fort Sherman Forest	Coco Solo Forest	Pacific Forest
Doliocarpus olivaceous					X
Erythrina			X		
Eugenia		X			
Ficus					X
Guatteria amplifolia			X		
Gustavia superba		X			
Heliconia		X 2 specie			X 2 specie
Hirtella americana			X	X	
Hirtella racemosa		X	X		X
Inga				X	X
Inga edulis		X			
Lacistemma aggregatum			X		
Licania arborea					X
Mabea occidentalis				X	
Miconia		X			
Miconia argentea		X			
Mouriri panamensis			X		
Myriocarpum yzabulensis		X			
Paulinia fibrigera			X		
Piper aequale		X			X
Piper cordulatum			X		
Piper hastularum			X		
Piper hispidum		X	X		
Piper reticulatum				X	X
Paulsenia armata		X			
P teium glabrum			X		
Proteium tennifolium		X			
Psychotria					X
Psychotria (2 species)		X			
Psychotria carthaginensis			X		
Psychotria chagrensis			X		
Psychotria pittieri			X		
Quassia amara				X	
Quararibea artrolepsis				X	
Rinorea sylvatica		X			
Stromanthe lutea				X	
Sorocea affinis					X
Tachigalia paniculata				X	
Talisis nervosa		X		X	
Theobroma purpureum		X			
Trichilia cipo				X	X
Triplaris cummingaiana					X
Virola nebilis		X			
Virola sebifera			X		
Vismia ferruginea		X			
Total species per 0.4 hectare	2	26	22	17	20

Vines (C-1 cont)

Vines

Species	Atlantic Mangrove	Gamboa Forest	Fort Sherman Forest	Coco Solo Forest	Pacific Forest
Ceratophylum tetragonalobium			X		
Cleomotoma viriabilis				X	
Clitoria		X		X	
Cycista aequinoctialis				X	
Dalchampsia panamensis			X		
Desmoncus isthmius			X		X
Doliocarpus olivaceous					X
Doxantha unquis-cati			X		
Gouania lupuloides			X		
Hiraea			X		
Machaerium seemanii					X
Mikania			X		
Passaflora vitiflora		X	X		
Paullinia baileyi			X		
Petrea volubilis			X		
Philodendron			X 2 specie	X	
Pithecoctenium echinatum			X		
Phryganicida corymbosa		X	X	X	
Pleonotoma viriabilis			X		
Serjania nessites		X	X		
Smilax			X		
Tetracera		X			
Total species per .04 hectare	0	5	17	5	3

Ground Cover (less than 1-meter high)

Species	Atlantic Mangrove	Gamboa Forest	Fort Sherman Forest	Coco Solo Forest	Pacific Forest
Adiantum			X	X	
Adiantum lucidum		X			X
Avicennia nitida	X				
Calathea		X		X	
Carludovica palmata		X			
Cyclanthus bipartitus		X			
Geonoma		X			
Laguncalaria racemosa	X				
Lygodium			X		
Gramineae (1 specie)				X	
Hysteria cf. costaricensis				X	
Peperomia			X		
Polypodium		X			X
Rhizophora mangle	X				
Sellaginella		X			
Swartzia simplex				X	
Tectaria				X	
Tectaria incisa		X			X
Total species per 0.4 hectare*	3	8	3	6	3

* Totals not significant as numerous seedlings were present in all plots that were unknown.

TABLE C-2. METEOROLOGICAL MEASUREMENTS AT THE EXPERIMENTAL AND ESTABLISHED TEST SITES

MEAN DAILY MAXIMUM TEMPERATURE (°F) — **SPECIAL PERIODS***

	1971									1972					Special Periods* 1971		1971		1972	
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	1-17 20 Apr	31 May	1-19 20 Nov	31 Dec	1-19 20 Jan	27 Feb
Forests																				
Mangrove	–	–	–	85	87	87	86	84	88	–	–	–	–	–	–	–	83	87	–	–
Gamboa	–	–	78	79	78	79	79	78	80	–	–	–	–	–	–	–	77	80	–	–
Ft. Sherman	85	82	79	80	82	80	83	79	83	81	83	83	80	83	84	83	78	82	81	83
Coco Solo	–	–	86	85	88	86	87	86	91	–	–	–	–	–	–	–	86	90	–	–
Pacific	–	73	79	82	81	82	81	81	81	–	–	–	–	–	–	–	81	81	–	–
Sheds																				
Coco Solo	–	–	85	85	87	87	86	83	87	–	–	–	–	–	–	–	86	83	–	–
Ft. Gulick	85	83	–	83	85	86	87	85	90	85	–	89	87	87	83	84	84	88	84	–
Chiva Chiva	–	82	84	84	85	85	83	85	87	86	88	90	89	85	–	–	84	87	85	–
Open																				
Ft. Sherman	89	88	87	85	88	88	86	84	86	84	88	90	83	91	88	88	83	86	83	87
Coco Solo	90	87	85	87	89	89	87	84	89	86	90	88	90	90	89	88	83	88	85	89
Ft. Gulick	92	87	84	85	88	86	88	85	87	85	83	90	89	88	91	88	84	87	84	88
Gamboa	92	87	83	83	83	86	87	86	89	86	91	87	87	85	93	89	86	88	87	90
Chiva Chiva	93	89	88	88	86	87	86	87	90	87	90	91	89	87	94	90	87	90	87	89
Gun Hill	90	85	84	86	86	84	86	84	88	86	88	90	88	88	90	86	84	87	85	87
Coastal																				
Atlantic	–	–	87	84	88	87	87	83	–	–	–	86	85	87	–	–	83	–	–	–
Pacific	–	–	85	85	85	86	86	86	88	87	89	85	86	87	–	–	86	87	87	89

* Note that the first time span of the "Special Periods" is much shorter than the second span.

MEAN DAILY MINIMUM TEMPERATURES (°F)

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	1-17 20 Apr	31 May	1-19 20 Nov	31 Dec	1-19 20 Jan	27 Feb
Forests																				
Mangrove	–	–	–	76	77	76	74	75	78	–	–	–	–	–	–	–	75	77	–	–
Gamboa	–	–	73	73	73	73	72	72	71	–	–	–	–	–	–	–	72	71	–	–
Ft. Sherman	80	78	77	78	79	76	78	75	79	78	78	78	75	78	80	79	75	78	78	78
Coco Solo	–	–	71	72	71	69	70	73	74	–	–	–	–	–	73	72	73	73	–	–
Pacific	–	73	74	76	75	76	76	75	70	–	–	–	–	–	–	–	76	71	–	–

Table C-2 (cont)

MEAN DAILY MINIMUM TEMPERATURE

	1971									1972					SPECIAL PERIODS* 1971		1971		1972	
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	1-17 20 Apr	31 May	1-19 20 Nov	31 Dec	1-19 20 Jan	27 Feb
Sheds																				
Coco Solo	–	–	73	75	75	73	73	72	74	–	–	–	–	–	–	–	73	71	–	–
Ft. Gulick	72	73	–	76	75	77	75	75	76	75	–	78	79	79	72	73	75	76	75	–
Chiva Chiva	–	72	75	74	73	73	71	72	70	72	72	71	73	73	–	–	73	71	72	–
Open																				
Ft. Sherman	78	76	76	74	75	75	72	71	–	77	78	78	79	78	78	77	71	–	77	80
Coco Solo	72	72	72	75	74	72	71	70	75	74	76	71	76	75	73	72	70	74	74	76
Ft. Gulick	73	73	72	73	74	72	71	70	69	72	72	73	75	68	73	73	70	69	72	72
Gamboa	64	68	71	72	71	72	72	72	69	70	71	66	70	70	66	67	72	70	76	72
Chiva Chiva	72	74	74	75	72	73	73	74	71	71	72	71	75	74	71	73	74	72	72	71
Gun Hill	71	72	71	74	73	71	72	70	72	74	74	74	75	76	71	72	71	72	75	73
Coastal																				
Atlantic	–	–	75	75	74	73	74	73	–	–	–	82	78	79	–	–	73	–	–	–
Pacific	–	–	77	76	76	76	76	75	75	75	76	72	75	77	–	–	75	75	75	76

* Note that the first time span of the "Special Periods" is much shorter than the second span.

MEAN TEMPERATURE (°F)

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	1-17 20 Apr	31 May	1-19 20 Nov	31 Dec	1-19 20 Jan	27 Feb
Forests																				
Mangrove	–	–	–	80	81	80	79	79	82	–	–	–	–	–	–	–	78	81	–	–
Gamboa	–	–	75	76	75	75	75	75	75	–	–	–	–	–	–	–	74	75	–	–
Ft. Sherman	82	80	78	79	80	78	80	77	81	79	80	80	77	–	82	81	76	80	79	80
Coco Solo	–	–	76	77	78	76	76	78	81	–	–	–	–	–	–	–	79	80	–	–
Pacific	–	76	76	78	78	78	78	78	74	–	–	–	–	–	–	–	79	75	–	–
Sheds																				
Coco Solo	–	–	78	79	80	79	78	77	79	–	–	–	–	–	–	–	77	78	–	–
Ft. Gulick	77	77	–	79	79	81	80	78	81	78	–	83	82	82	77	77	78	80	78	–
Chiva Chiva	–	76	78	78	77	78	76	77	78	78	79	79	79	78	–	–	78	78	78	–
Open																				
Coco Solo	79	78	77	80	80	79	77	76	81	79	82	77	81	81	79	79	76	80	79	81
Ft. Gulick	81	78	77	78	79	77	77	76	77	77	78	80	81	79	80	79	75	77	76	78
Gamboa	76	75	75	76	75	77	77	77	77	77	80	76	77	76	84	76	77	77	81	79
Chiva Chiva	81	79	79	80	77	78	78	79	79	78	79	80	80	79	82	79	79	79	78	77
Gun Hill	78	77	76	78	77	76	76	75	78	78	79	80	80	80	78	77	75	77	78	79

	1971									1972					1971		1971		1972	
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	1-17 20 Apr	31 May	1-19 20 Nov	31 Dec	1-19 20 Jan	27 Feb
MEAN DAILY MINIMUM TEMPERATURE															**SPECIAL PERIODS***					
Coastal																				
Atlantic	–	–	80	79	80	79	79	77	–	–	–	84	81	82	–	–	77	–	–	–
Pacific	–	–	80	79	79	80	80	79	80	79	81	77	79	80	–	–	79	80	79	81
MEAN TEMPERATURE RANGE (°F)																				
Forests																				
Mangrove	–	–	–	9	10	11	12	9	10	–	–	–	–	–	–	–	8	10	–	–
Gamboa	–	–	5	6	5	6	7	6	9	–	–	–	–	–	–	–	5	9	–	–
Ft. Sherman	5	4	2	2	3	4	5	4	4	3	5	5	5	5	4	4	3	4	3	5
Coco Solo	–	–	15	13	17	17	17	13	17	–	–	–	–	–	–	–	13	17	–	–
Pacific	–	6	5	6	6	6	5	6	11	–	–	–	–	–	–	–	5	10	–	–
Sheds																				
Coco Solo	–	–	12	10	12	14	13	11	13	–	–	–	–	–	–	–	13	12	–	–
Ft. Gulick	13	10	–	7	10	9	12	10	14	10	–	11	8	8	11	11	9	12	9	–
Chiva Chiva	–	10	9	10	12	12	12	13	17	14	16	19	17	12	–	–	11	16	12	–
Open																				
Ft. Sherman	11	12	11	11	13	13	14	13	–	7	10	12	10	13	10	11	12	–	6	7
Coco Solo	18	15	13	12	15	17	16	14	14	12	14	17	14	15	16	16	13	14	11	13
Ft. Gulick	19	14	12	12	14	14	17	15	18	13	16	17	14	20	18	15	14	18	12	16
Gamboa	28	19	12	11	12	14	15	14	20	16	20	21	17	15	27	22	14	18	11	18
Chiva Chiva	21	15	14	13	14	14	13	13	19	16	18	20	14	13	23	17	13	18	15	18
Gun Hill	13	13	13	12	13	13	14	14	16	12	14	16	13	12	19	14	13	15	10	14
Coastal																				
Atlantic	–	–	12	9	14	14	13	10	–	–	–	4	7	8	–	–	10	–	–	–
Pacific	–	–	8	9	9	10	10	11	13	12	13	13	11	10	–	–	11	12	12	13
MEAN DAILY MINIMUM RELATIVE HUMIDITY (PERCENT)																				
Forests																				
Mangrove	–	–	–	82	80	77	75	82	67	–	–	–	–	–	–	–	83	70	–	–
Gamboa	–	–	–	–	–	–	–	–	79	–	–	–	–	–	–	–	–	–	–	–
Ft. Sherman	74	84	88	85	88	87	83	86	79	84	75	73	82	–	74	81	82	81	87	76
Coco Solo	–	–	81	74	77	71	72	77	66	–	–	–	–	–	–	–	76	68	–	–
Pacific	–	87	85	84	85	87	86	86	71	–	–	–	–	–	–	–	91	75	–	–

Table C-2 (cont)

	MEAN DAILY MINIMUM RELATIVE HUMITITY														SPECIAL PERIODS*					
	1971									1972					1971		1971		1972	
Sheds	Apr	May	Jun	Jul	Aug	Sep	Oc.	Nov	Dec	Jan	Feb	Mar	Apr	May	1-17 20 Apr	31 May	1-19 20 Nov	31 Dec	1-19 20 Jan	27 Feb
Coco Solo	–	–	71	75	72	71	68	70	62	–	–	–	–	–	–	–	72	64	–	–
Ft. Gulick	65	78	–	78	69	70	69	73	67	71	–	59	70	68	64	74	75	67	74	–
Chiva Chiva	–	73	78	74	64	69	66	67	55	60	51	48	62	72	–	–	68	58	63	–
Open																				
Ft. Sherman	74	74	74	75	74	72	69	76	71	78	76	70	77	77	66	71	75	73	81	76
Coco Solo	60	66	73	73	68	73	64	71	65	69	–	59	73	71	60	64	72	66	71	–
Ft. Gulick	57	73	79	75	69	69	67	76	64	71	64	55	63	61	56	71	77	67	73	65
Gamboa	46	65	71	73	70	69	68	70	58	66	61	62	67	73	46	60	71	61	72	63
Chiva Chiva	48	69	68	65	71	69	66	65	54	63	54	41	60	70	44	64	67	57	67	57
Gun Hill	56	77	82	73	72	82	82	–	–	64	–	71	73	75	52	72	–	–	68	–
Coastal																				
Atlantic	–	–	–	–	69	79	70	69	–	–	–	–	–	–	–	–	79	–	–	–
Pacific	–	–	66	68	80	80	79	75	68	70	66	57	62	63	–	–	80	69	72	66
MEAN DAILY GLOBAL RADIATION (LANGLEYS PER DAY)																				
Open																				
Ft. Sherman	555	370	314	317	359	365	407	336	434	357	476	522	415	403	564	431	331	411	292	471
Coco Solo	579	350	316	307	321	338	–	286	–	–	–	544	416	373	591	413	270	309	–	–
Gamboa	–	–	–	–	–	351	–	298	–	322	414	467	375	351	–	–	–	–	340	413
Chiva Chiva	491	361	346	338	340	350	351	342	426	–	516	314	401	384	539	381	316	413	270	516
Coastal																				
Pacific	–	–	–	–	–	–	–	396	396	367	421	450	404	421	–	–	397	396	363	407
RAINFALL TOTAL (IN INCHES)																				
Open																				
Ft. Sherman	0.3	10.6	23.6	9.5	15.7	16.3	7.0	14.1	0.9	16.4	2.6	0.8	14.4	7.6	0.3	10.6	7.8	8.7	15.8	3.2
Coco Solo	0.2	10.3	17.6	14.4	18.6	13.7	20.1	15.7	0.8	8.0	3.1	0.8	8.1	7.0	0.2	10.5	10.2	6.3	7.3	3.7
Ft. Gulick	0.5	14.2	15.7	13.4	17.9	11.9	15.2	14.2	1.5	10.5	4.5	0.9	9.5	10.4	0.4	14.2	7.9	7.8	9.8	5.2
Gamboa	–	16.2	8.8	6.9	11.1	13.4	15.6	11.0	1.2	3.0	1.4	3.4	6.2	6.6	0	17.4	9.0	3.1	0.5	1.9
Chiva Chiva	3.4	9.5	4.8	7.0	12.3	8.9	11.3	9.7	0.2	6.0	0.3	1.9	9.8	8.9	0.1	12.4	7.3	2.5	6.0	0.3
Gun Hill	3.5	10.5	5.0	7.3	10.6	9.6	13.8	10.2	2.2	7.8	0.3	1.6	10.0	9.9	0.7	13.3	8.6	3.8	7.8	0.3
Coastal																				
Atlantic	–	–	19.6	14.0	18.7	14.3	20.0	12.4	0.6	9.1	3.8	0.8	9.5	8.4	–	–	8.5	4.4	8.5	4.4
Pacific	–	–	2.3	5.2	9.6	5.6	3.6	8.7	2.9	5.5	0	0.4	6.8	4.4	–	–	7.1	0	5.5	0

SALT FALL AT THE EXPOSURE SITE
($mg/m^2/day$)*

	1971 Jun	Jul	Aug	Sep	Oct	Nov	Dec	1972 Jan	Feb	Mar	Apr	May
Forest Sites												
Pacific (Ft. Clayton)	1.9	1.5	5.9	12.4	7.0	8.1	6.1	10.9	–†	–†	–†	–†
Gamboa	3.3	4.4	4.4	9.4	5.4	3.5	5.4	7.4	3.5	19.0	5.7	2.0
Coco Solo	4.9	3.4	8.5	10.2	5.8	–†	6.5	14.2	5.8	23.4	4.2	2.1
Ft. Sherman	.2	5.0	5.5	7.8	3.8	7.1	7.4	18.3	7.1	22.2	8.6	2.8
Average	2.58	3.58	6.08	9.95	5.50	6.23	6.35	12.70	5.47	21.53	6.17	2.30
Mangrove	3.5	3.8	4.3	4.9	8.9	7.5	15.2	30.1	6.8	65.8	4.3	4.8
Open and Sheltered Sites‡												
Chiva Chiva (O, S)	0.0	3.5	6.2	8.9	7.7	8.5	13.6	38.4	11.9	26.0	10.8	4.8
Gamboa (O)	1.6	2.6	4.1	9.8	20.8	4.6	9.3	10.3	4.2	19.0	9.1	3.6
Coco Solo (O, S)	1.2	3.2	7.7	11.0	–	5.7	7.0	9.5	8.2	27.2	8.4	2.0
Ft. Sherman (O)	4.7	10.5	16.7	15.2	6.8	–	44.7	61.4	28.0	62.0	22.1	6.0
Ft. Gulick (O, S)	3.7	6.9	8.6	10.8	5.7	10.1	12.6	15.4	8.2	31.7	12.1	3.8
Gun Hill (O)	1.1	4.1	11.1	4.8	7.6	16.2	–	12.7	5.0	21.5	9.3	3.4
Average	2.05	5.13	9.06	10.08	9.72	9.02	17.44	24.61	10.91	31.23	11.96	3.93
Coastal Sites												
Galeta	55.4	129.0	223.7	41.6	21.4	18.2	401.3	718.4	190.8	1008.4	505.6	133.9
Flamenco	5.1	3.8	37.0	21.5	5.6	–	8.7	11.2	–	22.3	10.7	6.3

* Salt fall is shown as milligrams/day, but is based on monthly exposure periods.

† Data missing because salt candles were destroyed in the field.

‡ O=open, S=sheltered (at Chiva Chiva, Coco Solo and Fort Gulick one salt candle site was established because of proximity of open and sheltered sites).

Table C-2 (cont)

Mean Wind Speed (mph) at Test Sites

1971	Chiva Chiva Open	Gun Hill Open	Coco Solo Open	Fort Sherman Open	
April	2	3	x	9	Dry Season
May	1	2	2	6	
June	1	2	2	6	
July	1	2	2	6	Wet Season
August	1	2	2	3	
September	2	2	x	4	
October	2	x	1	4	
November	< 1	x	1	4	
December	4	2	3	9	
1972	**Antenna Farm**				
January	3	3	2	8	
February	5	x	3	10	Dry Season
March	5	5	3	9	
April	5	4	3	9	
May	2	3	1	4	
June	2	2	1	5	Wet Season
July	3	2	x	8	

TABLE C-3. WHITE SANDS MISSILE RANGE MICROBIAL TEST EVALUATION SCHEME (PROPOSED)*

AMOUNT OF GROWTH	PERCENT OF AREA COVERED	GRADE	CONDITION OF SUBSTRATE: GROUP I ORGANIC SUBSTRATES	GROUP II ELASTOMERS AND COATINGS	GROUP III INORGANIC SUBSTRATES (GLASS AND METALS)†
None	O	O	Material is devoid of microbial growth. No change in substrate.	Substrate is devoid of microbial growth. No change in substrate.	Substrate is devoid of microbial growth. No change in substrate.
Trace	1–10	1	Sparse or very restricted microbial growth and reproduction. Substrate utilization minor or inhibited. Little or no chemical, physical or structural change(s) detectable. Serviceable (if used in contact with skin, replacement may be required).*	Sparse aerial growth on surface and few sites of colonization and penetration. Little or no chemical, physical or structural changes detectable. Serviceable (if used in contact with skin, replacement may be required).	Sparse intermittent infestations or loosely spread microbial colonies on substrate surface—with moderate reproduction. Tarnish, patina or surface film may be produced; few, small, localized pits may be observed. Serviceable.
Slight	11–30	2	Intermittent infestations or loosely spread microbial colonies on substrate surface, and moderate reproduction. Substrate effectively utilized, but chemical, physical or structural changes not readily observable. Generally serviceable and probable health hazard.	Loosely spread microbial colonies on substrate surface. Numerous points of colonization and penetration. Substrate is effectively utilized. Mycelia and reproduction are observable in air pockets and displaced substrate areas. Generally serviceable and possible health hazard.	Intermittent infestations to substantial amounts of microbial growth and reproduction on surfaces. A number of small pits, few large pits or striated pitting observable. Generally serviceable.
Moderate	31–70	3	Substantial amount of microbial growth and reproduction. Substrate exhibiting chemical, physical and/or structural change. Generally not serviceable and probable health hazard.	Substantial colony development and proliferation of colonies within the substrate. Chemical, physical and/or structural change observable and probable health hazard.	Substantial to massive amounts of microbial growth and reproduction observable. Extensive striated pitting, coalescence of large individual pits. Probably serviceable but recommend replacement in the near future.
Severe	71–100	4	Massive microbial growth and/or reproduction. Substrate decomposed or rapidly deteriorating. Not serviceable and probable health hazard.	Massive colony development and coalescence of colonies. Substrate no longer offers the protection required. Not serviceable and probable health hazard.	Massive microbial growth and reproduction. Extensive to complete displacement of metal (as leads of electronic boards) or possible etching of glass surfaces. Not serviceable.

* Earphones, microphones, telephone, clothing, helmets, etc.

† Readings are primarily based on substrate changes rather than microbial growth.

TABLE C-4. TAXONOMIC GROUPING OF FUNGI FOUND AT EXPOSURE SITES

Deuteromycetes (fungi imperfecti)

Moniliales

Moniliaceae		Dematiaceae		Tuberculariaceae		Dermophyta†		Pseudosaccharomycetes†		Yeast†	
*Cephalosporium**	919	*Aureobasidium**	3462	*Fusarium*	988	*Microsporum*	4	*Candida*	43	*Yeast*	956
*Gliocladium**	796	*Curvularia**	1369								
*Trichoderma**	579	*Nigrospora**	915								
*Paecilomyces**	564	*Hormodendrum**	449								
*Verticillium**	513	*Cladosporium**	122								
*Aspergillus**	293	*Spicaria**	95								
Cylindrocephalum	182	*Alternaria**	96								
*Peniccilium**	141	*Helminthosporium**	91								
Monilia	100	*Heterosporium**	61								
Oidium	60	*Menispora*	194								
Dactylaria	35	*Stemphylium**	43								
Stephanoma	25										
Monosporium	19										
Botrytis	18										
Total	4244		6897		988		4		43		956

Denteromycetes

Phomales

Leptostromaceae		Phomaceae	
Discosia	26	*Phoma**	34
Tota.	26		34

Phycomycetes

Spirogyrales

Mucoraceae

Rhizopus	15
Piptocephalis	1
*Choanephora**	124
Total	140

Schizomycetes

Actinomycetales

Actinomycetaceae		Streptomycetaceae	
Nocardia	42	*Streptomyces**	859
Total	42		859

* These organisms are or may be pigmented depending on the particular species referred to and/or the medium on which they are cultured.

† A morphological nontaxonmic grouping of organisms that do not fit well in any particular family.

TABLE C-5. FREQUENCY OF INCIDENCE OF MICROORGANISM ON TEST MATERIALS

NAME OF GENUS	Total†	Nylon	PVC	Butyl	Latex	Cotton	Coastal (2 Sites)	Open (5 Sites)	Shelter (3 Sites)	Forest (4 Sites)	Mangrove (1 Site)
Fungi*		Sum of all Sites					Average per Site				
Aureobasidium	3462	568	597	950	778	569	250	251	191	226	209
Curvularia	1369	289	214	28	326	539	106	116	127	40	65
Fusarium	988	219	203	176	75	315	30	53	92	82	58
Yeasts	956	268	[illegible]	308	83	64	53	61	45	79	98
Cephalosporium	919	182	182	238	173	144	17	43	74	97	62
Nigrospora	915	136	235	7	362	175	96	82	78	18	10
Streptomyces	859	149	113	47	306	244	61	65	47	57	40
Gliocladium	796	101	109	66	166	354	31	42	46	77	80
Trichoderma	579	173	225	72	19	90	13	25	26	57	93
Paecilomyces	564	146	195	108	73	42	29	26	52	42	54
Verticillium	513	130	97	102	132	52	5	19	38	66	30
Hormodendron	449	105	93	18	135	98	11	23	36	38	51
Aspergillus	293	73	90	33	71	26	9	11	14	40	19
Menispora	194	80	28	11	16	59	4	12	17	17	9
Cylindrocephalum	182	36	34	31	45	36	6	[illegible]	14	20	4
Penicillium	141	38	38	30	14	21	7	5	15	12	7
Choanephora	124	32	10	--	25	57	3	11	11	7	5
Cladosporium	122	13	12	3	73	21	9	7	5	13	3
Monilia	100	13	28	--	16	43	4	9	7	7	--
Alternaria	96	4	11	7	10	64	8	8	6	4	2
Spicaria	95	35	39	11	1	9	11	5	14	1	1
Helminthosporium	91	32	18	--	13	28	6	6	13	3	1
Heterosporium	61	21	29	2	9	--	3	3	7	4	1
Oidium	60	18	30	11	--	1	2	4	7	3	3
Stemphylium	43	5	11	--	10	17	2	3	6	1	1
Candida	43	10	16	6	11	--	2	3	6	1	1
Nocardia	42	19	17	4	2	--	1	--	--	8	5
Dactylaria	35	3	9	--	3	20	3	1	3	3	1
Others		Total Frequency of Incidence					782	903	997	1023	913
Bacteria	1494	322	414	327	121	310	91	87	84	117	157
Mites	468	46	22	26	305	69	21	32	34	33	29
Nematodes	187	9	8	5	84	81	4	3	11	28	19
Protozoa	23	3	9	7	1	2	--	2	1	3	1
							116	124	130	181	206

* In addition to the genus fungi listed the following were observed at reduced frequency (number of incidences in parentheses): *Botrytis* (18) mainly on cotton and latex; *Discosia* (26), mainly on latex, not on butyl; *Monosporium* (19), no preference; *Phoma* (34), some preference for cotton and nylon at open sites; *Rhizopus* (15), mainly on PVC and nylon, *Microsporum* (4); *Piptocephalis* (1); *Stephanoma* (25), mainly on PVC and butyl at open sites.

† Number of organisms.

NOTE: Data which are not significantly different at the 95% level have been connected by └──┘.

APPENDIX D. SOLAR ENERGY CALCULATION FOR PLANE DIRECTION AND INCLINATION

Daily sums of solar energy hitting a plane facing any of the 16 cardinal points and being inclined 0°, 15°, 30° . . . 90° on the horizontal plane, were obtained through the following computation.

Nomenclature

- a = azimuth of sun, counted from South = 0°
- h = elevation of the sun (h = 0 at the horizon, h-90° sun in the zenith)
- z = angle between the plane of the rack and the horizontal plane
- ϑ = angle between the direction which the rack faces and south
- ψ = angle under which the sunbeam hits the rack when the sun stands in direction a and elevation h

Cos ψ is directly proportional to the amount of solar energy under the assumption that there is no atmosphere, i.e., no attenuation by the air nor by clouds. The latter two effects are very difficult to take into consideration. The air itself has a relatively small effect because the sun is near the horizon only a short time. The clouds have a substantial effect; for the present case it is sufficient to assume that there are more clouds in the afternoon than there are before noon.

$$\cos \psi = \sin h \cos z + \cos h \sin z \cos (\vartheta - a)$$

This formula must be evaluated for many points, then weighted and summed up for different z's and ϑ's. In the numerical evaluation the declination progressed such that its value was taken on approximately the 7th and 22nd of each month (i.e., 13 values of ϑ) a and h progressed as time was incremented at 15-minute intervals. The above computations of cos ψ were averages over an entire year and converted to langleys/day. The results for each plane direction and inclination are displayed in table D-1 with the standard deviation for each position given in table D-2.

TABLE D-1. MEAN DAILY SOLAR ENERGY (IN LANGLEY/DAY) IMPINGING ON A PLANE OF GIVEN DIRECTION AND INCLINATION (ASSUMPTION: NO ATMOSPHERE)

PLANE IS FACING		S	SSE SSW	SE SW	ESE WSW	E W	ENE WNW	NE NW	NNE NNW	N	GRAND MEAN
PLANE IS INCLINED											
(Vertical)	z = 90°	253	284	370	428	428	377	276	163	124	300
	75°	401	436	506	552	548	490	389	272	237	424
	60°	576	599	642	669	657	603	513	420	377	560
	45°	727	739	759	766	751	708	642	576	548	697
	30°	832	836	840	840	825	790	755	720	708	794
	15°	$\boxed{895}$	887	883	875	867	852	836	830	829	860
(Horizontal)	0°	883	883	883	883	883	883	883	883	883	883

$\boxed{}$ = Maximum   [ ] = Positioning of the racks

TABLE D-2. RELATIVE SEASONAL VARIATION OF DAILY SOLAR ENERGY IMPINGING ON A PLANE OF GIVEN DIRECTION AND INCLINATION (ASSUMPTION: NO ATMOSPHERE)

PLANE IS FACING		S	SSE SSW	SE SW	ESE WSW	E W	ENE WNW	NE NW	NNE NNW	N
PLANE IS INCLINED										
(Vertical)	90°	108	81	41	16	5	24	51	96	138
	75°	81	61	30	13	6	24	47	87	133
	60°	51	41	24	9	7	21	41	68	88
	45°	32	27	16	6	7	19	32	49	57
	30°	18	15	9	4	8	16	24	32	36
	15°	6	5	4	5	8	12	16	20	19
	0°	8	8	8	8	8	8	8	8	8

Minimum, i.e., smallest seasonal variability

Positioning of the racks

Definitions: Percent Variation = $\frac{Sm}{M} \times 100$

M = Annual mean for the indicated inclination and direction

Sm = Standard deviation of the monthly values with respect to their annual mean, M.

NOTE: The Ms form the contents of above table.

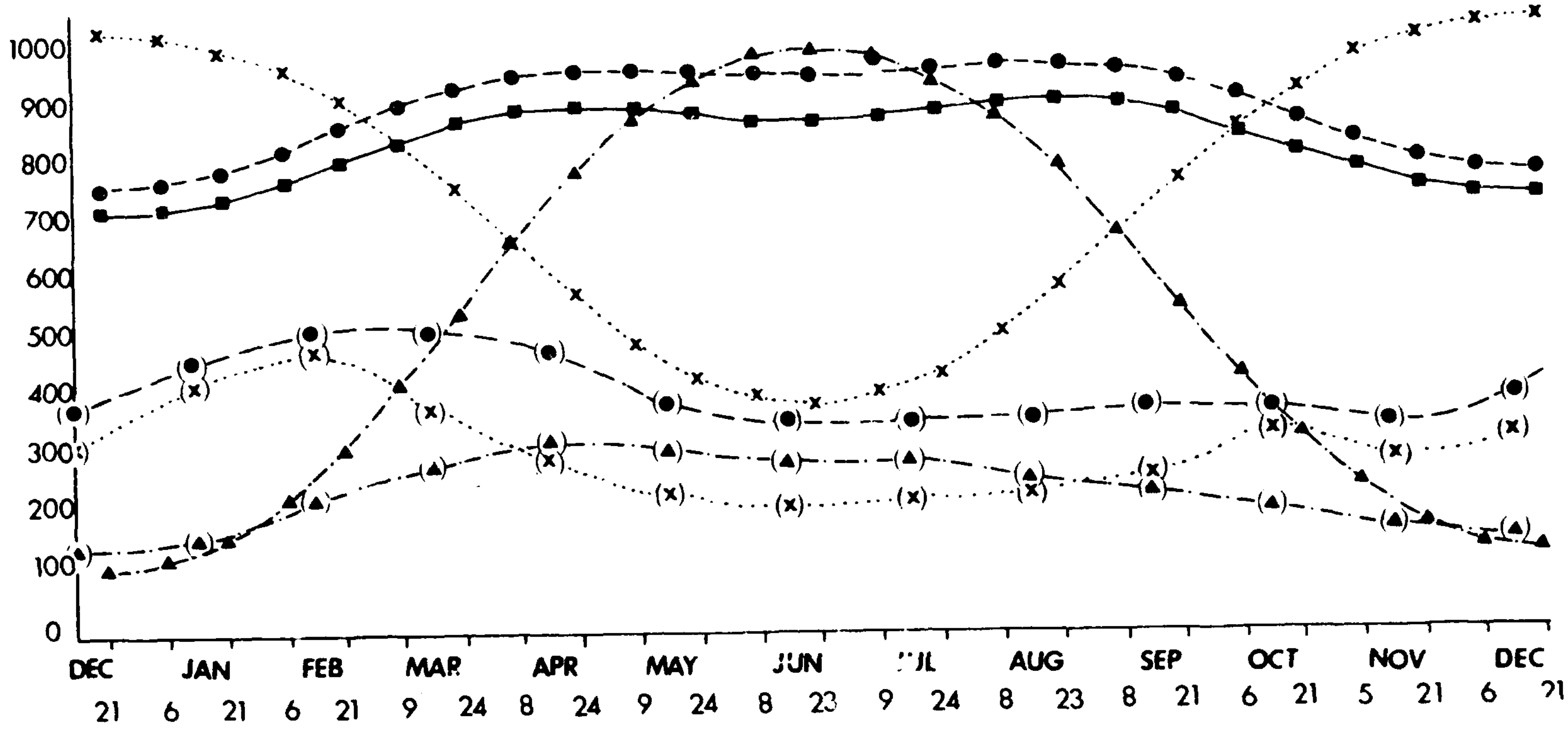
One can infer from table D-1 that the annual radiation impinging on racks facing east and inclined 30° would be, under the assumption of no atmosphere, 92 percent of the maximum possible. The exposure orientation used in many previous projects conducted in the Canal Zone, namely 45° inclination and facing south, would yield only 81 percent of the theoretically optimal exposure.

Table D-2 demonstrates that the positioning of the racks during this project had another advantage: Theory shows that the annual variation (standard deviation of the monthly values) is close to its minimum. This means that actual variations of the solar radiation were caused almost exclusively by climate and weather, but not by the seasonal movement of the sun.

Figure D-1 shows the annual variations of solar radiation for selected planes, and illustrates why the standard deviation on the racks was so small. In addition, this figure contains measured data which include, but are not confined to those which were collected during this project, i.e., past historical data.

Differences between computed and measured curves are due partly to the turbidity of the atmosphere, but mainly due to clouds. Turbidity does not necessarily reduce the radiation reaching a plane because it converts part of the direct solar radiation into diffuse skylight which also reaches the plane. The measurements that were made with radiometers facing north and inclined 45° show this effect.

Theoretically, the radiation on a plane facing eastward is equivalent to that incident on a plane facing westward when both have the same inclination. However, an eastward facing plane in the Canal Zone, as well as in most portions of the humid tropics, receives more radiation than a westward facing plane because cloudiness is usually less before noon than in the afternoon.



(Without parenthesis Assumption: no atmosphere; with parenthesis: Met Team data)

LEGEND

Symbol	■	●	(●)	x	(x)	▲	(▲)
plane facing	E or W		(●)	S	S	N	N
plane inclined	30°	0°	0°	45°	45°	45°	45°
remarks	rack position	horizontal plane	(measured)		(measured)		(measured)

Figure D-1. Annual Variation of Solar Radiation on Selected Planes (Langley/Day).